VOL. 79 MAY, 1956

TRANSACTIONS OF THE ROYAL SOCIETY OF SOUTH AUSTRALIA

INCORPORATED

ADELAIDE

PUBLISHED AND SOLD AT THE SOCIETY'S ROOMS
KINTORE AVENUE, ADELAIDE

Registered at the General Post Office, Adelaide,
for transmission by post as a periodical.

ROYAL SOCIETY OF SOUTH AUSTRALIA

INCORPORATED

OFFICERS FOR 1955-1956

Patron:

HIS EXCELLENCY AIR VICE-MARSHAL SIR ROBERT GEORGE, K.C.V.O., K.B.E., C.B., M.C.

President:

C. G. STEPHENS, D.Sc.

Vice-Presidents:

I. M. THOMAS, M.Sc.

R. V. SOUTHCOTT, M.B., B.S.

Secretary:

L. W. PARKIN, M.Sc., A.S.T.C.

Treasurer:

H. M. HALE, O.B.E.

Editor:

J. A. PRESCOTT, D.Sc., A.I.C., C.B.E., F.R.S.

Librarian:

N. B. TINDALE, B.Sc.

Programme Secretary:

S. J. EDMONDS, B.A., M.Sc.

Members of Council:

S. B. DICKINSON, M.Sc.
I. G. SYMONS
T. R. N. LOTHIAN, N.D.H.
D. C. SWAN, M.Sc.
A. R. ALDERMAN, D.Sc., Ph.D., F.G.S.
C. M. DELAND, M.B., B.S.

Auditors:

F. M. ANGEL

N. S. ANGEL

THE MOLLUSCAN FAUNA OF THE PLIOCENE STRATA UNDERLYING THE ADELAIDE PLAINS PART 111-SCAPHOPODA, POLYPLACOPHORA, GASTROPODA (HALIOTIDAE TO TORNIDAE)

BY N. H. LUDBROOK

Summary

Part III of the study of the mullusca from borings into the Dry Creek Sands consists of a revision of the Scaphopoda, Polyplacophora, and the gastropod families from the Haliotidae to the Tornidae, i.e., the superfamilies Pleurotomariacea, Cocculinacea, Littorinacea, and Rissoacea. The nomenclature of 43 species has been revised and 17 new species have been described. The geological background and relationships of the fauna were discussed in Part I, published in the Transactions of the Society, 77, pp. 42-64, 1954.

THE MOLLUSCAN FAUNA OF THE PLIOCENE STRATA UNDERLYING THE ADELAIDE PLAINS

PART III—SCAPHOPODA, POLYPLACOPHORA, GASTROPODA (HALIOTIDAE TO TORNIDAE)

by N. H. LUDBROOK*

[Read 14 April 1955]

SUMMARY

Part III of the study of the mollusca from borings into the Dry Creek Sands consists of a revision of the Scaphopoda, Polyplacophora, and the gastropod families from the Haliotidae to the Tornidae, i.e., the superfamilies Pleurotomariacea, Cocculinacea, Littorinacea, and Rissoacea. The nomenclature of 43 species has been revised and 17 new species have been described.

The geological background and relationships of the fauna were discussed in Part I, published in the Transactions of the Society, 77, pp. 42-64, 1954.

INTRODUCTION

As with the Pelecypoda (Part 2 of this series, published in vol. 78, 1955, pp. 18-87) diagnoses of species have been made, wherever possible, from the holotypes. Where these were not available, Dry Creek Sands examples have been used. Dimensions cited are those of the holotype.

Abbreviations employed were listed in Part 2—Pelecypoda.

Class SCAPHOPODA Bronn, 1862
Family DENTALIIDAE Gray, 1847
Genus DENTALIUM Linné, 1758

Dentalium Linné, 1758. Syst. Nat., ed. 10, p. 785.

Type species (s.d. Montfort, 1810) *Dentalium elephantinum* Linné.

Subgenus DENTALIUM s. str.

(*Paradentalium*, Cotton & Godfrey, 1933. S. Aust. Nat., 14, (4), p. 139.)

Dentalium (Dentalium) latesulcatum Tate

pl. 1, figs. 10-14.

Dentalium elephantinum Linné. Tate, 1890. Trans. Roy. Soc. S. Aust. **13**, (2), p. 177.
Dentalium octogonum Lamarck. Tate, ibid.
Dentalium sectum Deshayes. Tate, ibid.
Dentalium latesuclatum (err. pro *latesulcatum*) Tate, 1899. Trans. Roy. Soc. S. Aust. **23**, (2), p. 262, pl. 8, fig. 9 (*latesulcatum*).
Dentalium latesulcatum Tate. Dennant & Kitson, 1903. Rec. Geol. Surv. Vic., **1**, (2), p. 138.
Dentalium intercalatum Gould. Howchin, 1936. Trans. Roy. Soc. S. Aust., **60**, p. 16.
Dentalium intercalatum aratum Tate. Howchin, ibid.
Dentalium intercalatum franciscense Verco. Howchin, ibid.
Dentalium intercalatum var. Howchin, ibid., p. 17.
Dentalium sp. Howchin, ibid.
Dentalium (*Paradentalium*) *latesulcatum* Tate. Cotton & Ludbrook, 1938. Trans. Roy. Soc. S. Aust., **62**, (2), p. 224.
Dentalium (*Paradentalium*) *howchini* Cotton & Ludbrook, ibid.
Dentalium (*Paradentalium*) *howchini* Cotton & Ludbrook. Ludbrook, 1941. Trans. Roy. Soc. S. Aust., **65**, (1), p. 101.

* Department of Mines, Adelaide. Published with the permission of the Director of Mines.

Dentalium (*Dentalium*) *howchini* Cotton & Ludbrook. Ludbrook, 1954. Trans. Roy. Soc. S. Aust., 77, p. 58.

Diagnosis—Shell large, thick and solid, with 7 to 16 strong primary ribs approximately equal to interspaces in which secondary ribs are often developed by intercalation.

Dimensions—Length 40, breadth 7 mm.

Type Locality—Grange Burn, Hamilton, Victoria; Pliocene.

Location of Holotype—Tate Mus. Coll. Univ. of Adelaide, T1610.

Observations—Re-examination of the type material of *Dentalium* (*Paradentalium*) *howchini* Cotton & Ludbrook has failed to reveal to the writer any diagnostic characters to distinguish that species from Tate's *latesulcatum* of the Pliocene, Grange Burn near Hamilton, Victoria. The species carries an extremely variable number of primary ribs, original specimens having 9 to 12, while those from Abattoirs Bore (type of *howchini*) show a range of from 7 to 16, about 12 being the most usual. In adult specimens the primary ribs may be broken by longitudinal grooves (pl. 1, fig. 10a). Ribs and interspaces are crossed to a greater or lesser extent by growth striae which are conspicuously developed in the interspaces.

The degree of curvature of the shell is also somewhat inconstant. Shells retaining the juvenile apical portion appear to be more strongly curved than those which have lost it. The extent of variation in shell characters is illustrated (pl. 1, figs. 10-14).

The subgenus *Paradentalium* created by Cotton & Godfrey for *D. bednalli* Pilsbry & Sharp (incorrectly identified as *D. intercalatum* Gould) proves on examination of ample material in the British Museum to be a synonym of *Dentalium* s. str. The general characters of *Dentalium latesulcatum* are more closely related to those of the type species *D. elephantinum* than to those of any living southern Australian species. The resemblance between the present species and the Recent Indo-Pacific species was previously masked by the use of *Paradentalium* for the Pliocene shell.

Material—Holotype and 6 paratypes of *latesulcatum*; holotype and numerous paratypes of *howchini*; 1 specimen Thebarton Bore.

Stratigraphical Range—Pliocene.

Geographical Distribution—Gippsland, Vic., to Adelaide, S. Aust.

Subgenus Fissidentalium Fischer, 1885.

Fissidentalium Fischer, 1885. Man. de Conch., p. 894.
(*Schizodentalium* Sowerby, 1894. Proc. Mal. Soc. I, p. 158.)

Type species (monotypy) *Dentalium ergasticum* Fischer.

Dentalium (Fissidentalium) mawsoni sp. nov.

pl. 1, figs. 5, 6.

Dentalium kicksii Nyst. Tenison Woods, 1876. Proc. Roy. Soc. Tas. for 1875, p. 15.
Entalis mantelli Zittel. Tate, 1887. Trans. Roy. Soc. S. Aust., 9, p. 190.
Entalis mantelli Zittel. Tate & Dennant, 1893, id., 17, (1), p. 223.
Entalis mantelli Zittel. Tate & Dennant, 1895, id., 19, (1), p. 112.
Entalis mantelli Zittel. Pritchard, 1896. Proc. Roy. Soc. Vic., 8, (n.s.), p. 126.
Dentalium mantelli Zittel. Harris, 1897. Cat. Tert. Moll. Brit. Mus. (1), p. 293.
Dentalium (*Fissidentalium*) *mantelli* Zittel. Tate, 1899. Trans. Roy. Soc. S. Aust., 23, (2), p. 261.
Dentalium (*Entalis*) *mantelli* Zittel. Howchin, 1936, id., 59, pp. 74, 75.
Dentalium (*Fissidentalium*) *mantelli* Zittel. Cotton & Ludbrook, 1938, id., 62, (2), p. 222.

Diagnosis—Shell moderately large, generally thick, stout, almost straight. Sculpture of 23 fine longitudinal ribs at the apex, increasing in number to 50 at the aperture. Ribs near apex narrower than or approximately equal to interspaces. Secondary ribs rise in interspaces.

Description of Holotype—Shell of moderate size, fairly thick, stout, tapering, slightly curved near the apex then almost straight for the rest of the shell. Sculpture of 23 fine longitudinal ribs at the apex, with secondary ribs rising by intercalation between them at a distance of about 15 mm. from the apex; about 50 ribs at the aperture. Longitudinal sculpture crossed and faintly tuberculated by numerous, crowded, transverse growth striae. Apex circular with a long, narrow fissure, aperture circular, peristome thin in holotype.

Dimensions—Length 41·5, apical diameter 1, apertural diameter 4 mm.

Paratype—A smaller specimen (pl. 1, fig. 6) showing curvature near apex. Length 38·5, diameter at aperture 3 mm.

Type Locality—River Murray Cliffs (?Morgan), Miocene.

Location of Types—Tate Mus. Coll. Univ. of Adelaide, F15139.

Observations—Sufficient material is available in the British Museum for comparisons to be made between Australian examples of so-called *mantelli* from various localities and specimens of true *mantelli* from Onekakara, N.Z., one of which may be the specimen figured by Mantell in 1850 (pl. 28, fig. 15). There is no doubt of the close resemblance between the two. The Australian shells are, however, straighter than the one New Zealand shell which is sufficiently unbroken for the curvature to be determined. This is a large shell 70 mm. in length, with the apical portion (about 20 mm.) missing. The tendency in Australian examples is for any curvature to be developed near the apex and not over the shell generally. Sculpture is very similar in both species, ribbing in the New Zealand *mantelli* being, on the whole, broader in relation to the interspaces.

The species is represented in the Dry Creek Sands by 4 fragments from Weymouth's Bore; as more than one species may be listed under the name in the literature, its geographical distribution is here limited to those localities at which it is definitely known by the writer to occur.

Material—Holotype and 5 paratypes "River Murray Cliffs" (?Morgan); 3 paratypes Pliocene Blanche Point, Aldinga Bay; Tate Mus. Coll. Univ. of Adelaide. 3 fragments Weymouth's Bore, Mines Dept. Coll., 4 paratypes G9367, Lower Beds, Muddy Creek, Brit. Mus. Coll.

Stratigraphical Range—Tertiary, not accurately determined.

Geographical Distribution—Muddy Creek, Victoria; South Australia.

Subgenus Antalis Adams (H.) & Adams (A.)

Antalis H. & A. Adams, 1854. Gen. Rec. Moll., p. 45.
(*Entalis* Gray, 1847. Proc. Zool. Soc., p. 158, *non* Sowerby, 1839.)
(*Entaliopsis*, Newton & Harris, 1894. Proc. Malac. Soc., 1, (2), p. 66.)

Type species (s.d. Pilsbry & Sharp, 1897) *Dentalium entalis* Linné.

Dentalium (Antalis) denotatum sp. nov.

pl. 1, figs. 7-9.

Dentalium (*Fissidentalium*) *bifrons* Tate. Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 101.

Diagnosis—A small, slender *Antalis* sculptured near the apex with about 16 primary riblets with finer secondary threads developing by intercalation, all becoming obsolete in the apertural one-third. Shell moderately curved and gradually tapering.

Description of Holotype—Shell small, slender, thin but solid, gently curved and gradually tapering; section rounded. Sculpture of 16 fine primary riblets at the apex and finer secondary threads in the interspaces. Sculpture becoming obsolete towards the aperture. Growth lines slightly oblique, stronger near the aperture. Apex small, thick, circular, with a small notch. Aperture circular, peristome thin, sharp.

Dimensions—Length 24, diameter at apex 1·4, diameter at aperture 2·9 mm., arc 1 mm.

Type Locality—Abattoirs Bore; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, F15140.

Observations—Previously these small shells have been taken to be juveniles of the large *D. bifrons* Tate. The two, however, are distinct, the present species being a typical small *Antalis*, generally with a slight apical notch or supplementary pipe. *Dentalium* (*Fissidentalium*) *bifrons* was inadvertently included in the author's list (1954, p. 58).

Material—Holotype, 2 figured paratypes and 12 paratypes, 8 fragments Abattoirs Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Abattoirs Bore.

Family SIPHONODENTALIIDAE Simroth, 1894.

Genus Siphonodentalium M. Sars, 1859.

Siphonodentalium M. Sars, 1859. Forh. Vidensk.-Selks., 1858, p. 52.

Type species (o.d.) *Dentalium lobatum* Sowerby (= *S. vitreum* Sars).

Subgenus Pulsellum Stoliczka, 1868.

Pulsellum Stoliczka, 1868. Cret. Fauna S. India, **2**, p. 441.

Type species (s.d. Pilsbry & Sharp, 1897) *S. lofotense* M. Sars.

Siphonodentalium (Pulsellum) adelaidense sp. nov.

pl. 1, fig. 1.

Diagnosis—Shell largest at the aperture, tapering at first rapidly and then very gradually towards the apex.

Description of Holotype—Shell small, thin, smooth, shining, gently curving, tapering rapidly from posterior aperture for about one-third the length of the shell, thence gradually tapering to the apex. Aperture subcircular, widely open; apex entire, round, without slits.

Dimensions—Length 6·4 mm.; diameter at aperture 1 mm.; diameter at apex 0·4 mm.

Type Locality—Hindmarsh Bore, 450-487 feet; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, F15141.

Observations—This is the first record of the genus in southern Australia. It may escape notice on account of its possible resemblance to a *Cadulus* from which the anterior portion has been broken. In contrast with *Cadulus*, which is constricted at both the anterior and posterior openings, *Siphonodentalium* is the largest at the aperture, which is generally widely opened. The genus has a wide distribution in Recent waters, mainly European, North American, and Indo-Pacific, including Northern Australia, though apparently not in large numbers.

Material—Holotype and 3 paratypes, Hindmarsh Bore; 1 paratype, Weymouth's Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Hindmarsh and Weymouth's Bores.

Genus Cadulus Philippi, 1844.

Cadulus Philippi, 1844. Enum. Moll. Sicil., **2**, p. 209.

Type species (monotypy) *Dentalium ovulum* Philippi.

Subgenus Dischides Jeffreys, 1867.

Dischides Jeffreys, 1867. Ann. Mag. Nat. Hist., ser. 3, **20**, p. 251.

Type species (o.d.) *Cadulus politus* S. V. Wood.

Cadulus (Dischides) yatalensis sp. nov.

pl. 1, figs. 3, 4.

Cadulus mucronatus Tate. Ludbrook, 1941. Trans. Roy. Soc. S. Aust., **65**, (1), p. 101.

Diagnosis—Long and slender *Dischides*, not conspicuously swollen, curved and very gradually tapering at each end.

Description of Holotype—Shell fairly small, solid, very slender, smooth, shining, gently arcuate, more so on the ventral convex side than on the dorsal surface. Contraction towards the anterior aperture only slight, over a length of about 1 mm.; contraction towards the posterior apex gradual, from 1 mm. to 0.8 mm. over a length of 3·5 mm. Aperture oblique, with a thin, sharp edge; apex small, oblique, divided into 2 lobes by two lateral slits; the ventral lobe is larger, is conspicuously thickened and mucronately produced; the dorsal lobe is smaller and not thickened within.

Dimensions—Length 9·2 mm.; greatest diameter 1·6 mm.; diameter at aperture 1·4 mm.; diameter at apex 0·8 mm.

Type Locality—Weymouth's Bore, 310-330 feet, Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, F15142.

Observations—This is a larger, longer, and much more slender species than *C. mucronatus* or *C. acuminatus*. It is distinguished by these features, the usual absence of swelling or bulge, and by the two apical slits. The two specimens (one figured, pl. 1, fig. 4), previously identified as *C. mucronatus*, are a little less slender than the typical species.

Material—Holotype, 10 paratypes, 4 fragments Weymouth's Bore; 3 paratypes, 9 fragments Hindmarsh Bore; 2 paratypes Abattoirs Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Adelaide District.

Subgenus Gadila Gray, 1847.

Gadila Gray, 1847. Proc. Zool. Soc., p. 159.

Type species (o.d.) *Dentalium gadus* Montagu.

Cadulus (Cadila) acuminatus Tate

pl. 1, fig. 2.

Cadulus acuminatus Tate, 1887. Trans. Roy. Soc. S. Aust., 9, p. 194.
Cadulus (Gadila) acuminatus Tate, 1899, id. 23, (2), p. 266, pl. 8, fig. 12.
Cadulus acuminatus Desh. Dennant & Kitson, 1903. Rec. Geol. Surv. Vic., 1, (2), p. 143.
Cadulus acuminatus Tate. Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 101.

Diagnosis—Very small, curved, gently tapering at both ends, not bulging, both aperture and apex circular.

Dimensions—Length 6 mm.; diameter at about the middle 1 mm.; diameter of aperture 0·75 mm.

Type Locality—Oyster Beds, Aldinga Bay, Pliocene.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, No. T231.

Material—Holotypes and 2 paratypes; 4 specimens Dry Creek Bore 320 feet, 4 specimens Dry Creek Bore 340 feet; 2 specimens Abattoirs Bore 340 feet.

Stratigraphical Range—Pliocene of Aldinga Bay and Dry Creek Sands.

Geographical Distribution—Aldinga; Dry Creek, Abattoirs, and Hindmarsh Bores, Adelaide, S.A.

Class POLYPLACOPHORA

Order CHITONIDA

Family CRYPTOPLACIDAE

Subfamily Acanthochitona Gray, 1821.

Acanthochitona Gray, 1821. Lond. Med. Repos., 15, p. 234.
Acanthochites Risso, 1826. Hist. Nat. Europe, 4, p. 268.
Phakellopleura Guilding, 1830. Zool. Journ., 5, (10), p. 28.
Acanthochitus, Philippi, 1844. Anim. Moll. Sicil., 2, p. 83.
Acanthochiton Herrmannsen, 1846. Ind. Gen. Malac., 1, p. 2.
? *Hamachiton* + *Platysemus* Middendorff, 1848. Mem. Acad. imp. Sci. St. Petersbourg, ser. 6, 8, (2), pp. 97, 98.
Stectoplax Dall, 1882. Proc. U.S. Nat. Mus., 4, p. 284.
Anisochiton P. Fischer, 1885. Man. de Conch., p. 881.

Type species (by monotypy) *Chiton fascicularis* Linné.

Subgenus EOPLAX Ashby & Cotton, 1936.

Eoplax Ashby & Cotton, 1936. Rec. S. Aust. Mus., **5**, (4), p. 510, fig. 2.

Acanthochitona (Eoplax) adelaidae Ashby & Cotton

Acanthochiton (Eoplax) adelaidae Ashby & Cotton, 1936. Rec. S. Aust. Mus. 5, (4), fig. 2.
Eoplax adelaidae Ashby & Cotton, 1936. Cotton & Godfrey, 1940. Moll. S. Aust., **2**, p. 575.
Eoplax adelaidae Ashby & Cotton. Cotton & Weeding, 1941. Rec. S. Aust. Mus., **6**, (4), pp. 441, 443.

Diagnosis (from one rather worn median valve)—Valve carinated, angle of divergence 90°. Pleural and lateral areas inseparable, the tegmentum laterally much reduced. Sculpture of pleural area terminating anteriorly at 1·5 mm. from the anterior margin of the dorsal area consists of longitudinal rows of flat, triangular, scale-like granules.

Insertion plates very broad, showing a strong calloused broad ridge commencing at the slit and ending on one side of the tegmentum.

Dimensions—Length 7 mm.; width 7·5 mm.

Type Locality—Torrensville Bore, 490 feet; Dry Creek Sands.

Location of Holotype—S. Aust. Mus. Reg. No. 12882 (P.10159).

Material—Holotype.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Torrensville Bore, 490 feet.

Family CHITONIDAE.

Subfamily CHITONINAE.

Genus CHITON Linné, 1758.

Chiton Linné, 1758, Syst. Nat., ed. 10, p. 667.

Type species (s.d. Children, 1823) *Chiton squamosus* Linné.

Subgenus ANTHOCHITON Thiele, 1893.

Anthochiton Thiele, 1893, in Troschel Gebiss Schneck, **2**, p. 377.

Type species (monotypy) *Chiton tulipa* Quoy & Gaimard.

Chiton (Anthochiton) relatus Ashby & Cotton

Chiton (Anthochiton) tricostalis relata Ashby & Cotton, 1936. Rec. S. Aust. Mus., **5**, (4), p. 509, fig. 1.
Anthochiton relatus Ashby & Cotton. Cotton & Godfrey, 1940. Moll. S. Aust., **2**, p. 575.
Anthochiton relatus Ashby & Cotton. Cotton & Weeding, 1941. Rec. S. Aust. Mus., **6**, (4), pp. 442, 444.

Diagnosis (from one worn median valve)—Angle of divergence 80°. Pleural area transversed longitudinally by twelve shallow, broad grooves and corresponding ridges. Lateral areas with two strong, broad ribs, the anterior bifurcating, each with 10 broad tubercles. Surface of tegmentum on erosion perforated with numerous small pits.

Dimensions—Length 3·5 mm.; width 6·5 mm.

Type Locality—Torrensville Bore, 490 feet; Dry Creek Sands.

Location of Holotype—S. Aust. Mus. Reg. No. D.12883 (P.10157).

Material—Holotype.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Torrensville Bore, Adelaide District.

Subfamily CRYPTOPLACINAE.

Genus CRYPTOPLAX Blainville, 1818.

Cryptoplax Blainville, 1818. Dict. Sci. Nat., **12**, p. 124.
(*Chitonellus* Lamarck, 1819. Anim. s. vert., **6**, (1), p. 317.)
(*Oscabrella* Partington, 1835. Brit. Cyclop. Nat. Hist., **2**, (14), p. 31.)
(*Chitoniscus* Herrmannsen, 1846. Ind. Gen. Malac., **1**, p. 230.)

Type species (s.d. Herrmannsen, 1852) *Chiton larvaeformis* Burrow.

Cryptoplax ludbrookae Ashby

Cryptoplax ludbrookae Ashby, 1940. Trans. Roy. Soc. S. Aust., **64**, (2), p. 266. text-fig.
Cryptoplax ludbrookae Ashby, Cotton & Godfrey, 1940. Moll. S. Aust., **2**, p. 575.
Cryptoplax ludbrookae Ashby. Cotton & Weeding, 1941. Rec. S. Aust. Mus., **6**, (4), pp. 442, 444.

Diagnosis (from one head valve)—Sculpture of tegmentum consisting of granules somewhat irregularly arranged in longitudinal rows; beak overhanging, almost smooth to subgranular, granules near to the apex circular and subrounded, increasing in size, anteriorly flattened, elliptical or oblong in the central anterior portion.

Insertion plate extending well forward beyond the tegmentum for one-third length of tegmentum.

Dimensions—Length 1·2 mm.; width 1·3 mm.

Type Locality—Holden's Motor Body Works Bore, Woodville, Adelaide District, 335-380 feet; Dry Creek Sands.

Location of Holotype—S. Aust. Mus. Reg. No. P. 4285.

Material—Holotype.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Holden's Motor Body Works Bore, Woodville.

Class GASTROPODA
Subclass PROSOBRANCHIA.
Order ARCHAEOGASTROPODA
Superfamily PLEUROTOMARIACEA
Family HALIOTIDAE.
Genus Haliotis Linné, 1758.

Haliotis Linné, 1758. Syst. Nat., ed. 10, p. 779.
(*Teinotis* H. & A. Adams, 1854. Gen. Rec. Moll. 1, p. 442.)
(*Tinotis* P. Fischer, 1885. Man. Conch., p. 845.)

Type species (s.d. Montfort, 1810) *Haliotis asinina* Linné.

Subgenus Notohaliotis Cotton & Godfrey, 1933.

Notohaliotis Cotton & Godfrey, 1933. S.A. Nat., **15**, (1), p. 16.

Type species (o.d.) *H. naevosa* Martyn = *Haliotis ruber* Leach.

Haliotis (Notohaliotis) naevosoides McCoy

Haliotis naevosoides McCoy, 1876. Prod. Pal. Vict., 3, p. 27, pl. 26, figs. 1, 2a.
Haliotis naevosoides McCoy, R. Etheridge, jr., 1878. Cat. Aust. Foss., p. 164.
Haliotis naevosoides McCoy, Harris, 1897. Cat. Tert. Moll. Brit. Mus., p. 285.
Haliotis naevosoides McCoy, Dennant & Kitson, 1903. Rec. Geol. Surv. Vic., 1, (2), pp. 117, 138.

Diagnosis—Suborbicular, depressed, whorls flattened between the suture and perforations. Upper surface with radiating ridges extending a little more than halfway between the suture and the perforations, about 12-14 mm. long with adult whorls, somewhat concave towards the aperture. Perforations about one per radial, about 5 mm. apart. Spiral striae thick, about 1 mm. apart.

Type Locality—Flemington, Melbourne.

Location of Holotype—Geological Survey, Victoria Coll.

Material—3 topotypes. 3 specimens Maynes Quarry, Vic., B.M. Coll. 1 juvenile Abattoirs Bore.

Observations—The identification of this species is doubtful.

Stratigraphical Range—Not accurately known.

Geographical Distribution—Melbourne, Victoria; Adelaide, S.A.

Family FISSURELLIDAE
Subfamily Emarginulinae.
Genus Emarginula Lamarck, 1801.

Emarginula Lamarck, 1801. Syst. Anim. s. Vert., p. 69.
(*Emarginulus* Montfort, 1810. Conch. Syst., **2**, p. 75.)

(*Emarginula* Gray, 1821. Lond. Med. Repos., p. 233.)

Type species (monotypy) *E. conica* = *Patella fissura* Linné.

Emarginula didactica sp. nov.

pl. 2, fig. 2.

Emarginula candida A. Adams. Tate, 1890a. Trans. Roy. Soc. S. Aust., 13, (2), p. 177.
Emarginula candida A. Adams. Dennant & Kitson, 1903. Rec. Geol. Surv. Vic., 1, (2), p. 145.
Emarginula candida Adams. Ludbrook, 1941. Trans. Roy. Soc. S. Aust., **65**, (1), p. 100.

Diagnosis—Shell small, elliptical, depressed posteriorly, strongly convex anteriorly, fairly high. Apex at posterior one-fifth, elevated, protoconch smooth, recurved posteriorly. Sculpture of about 14 primary radial riblets between which are secondary ribs of varying strength, crossed by about 16 concentrics producing a clathrate ornament. Slit fasciole situated between two ridges, callus formed of concave lamellae.

Description of Holotype—Shell elongate elliptical, conical, apex at posterior one-fifth; protoconch smooth, recurved posteriorly; sculptured with 14 primary radiating ribs, scaly, imbricating with secondary ribs between particularly at posterior end, crossed by about 16 concentrics, producing a clathrate sculpture. Slit fasciole between two ridges; callus of distinct concave lamellae.

Dimensions—Length 5; maximum width 3; altitude 2·5; length of aperture 0·6 mm.

Type Locality—Abattoirs Bore, Adelaide, S. Aust.; Dry Creek Sands.

Location of Types—Tate Mus. Coll., Univ. Adelaide, F 15143.

Material—Holotype, portion of one paratype, Abattoirs Bore; 2 paratypes, Hindmarsh Bore.

Observations—This species, previously referred to the Recent *E. candida*, has now been compared with the holotype of that species. The fossil species is narrower than *candida*; it is more coarsely sculptured, having only 14 radial ribs as against 20 in *candida*. The apex is nearer the posterior margin and the fissure is lamellose, not marked by a strong rib as in *candida*. Its nearest fossil ally is *E. dennanti*, which is wider, and has 24 primary radials.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Adelaide District.

Emarginula delicatissima Chapman & Gabriel

Emarginula delicatissima Chapman & Gabriel, 1923. Proc. Roy. Soc. Vic., **36** (n.s.), (1), p. 26, pl. 1, figs. 11, 12; pl. 3, figs. 30, 31.
Emarginula delicatissima Chapman & Gabriel. Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 100.
Emarginula delicatissima Chapman & Gabriel. Crespin, 1943. Min. Res. Surv. Bull. 9, p. 96.

Diagnosis—Elongate-ovate, depressed, apex close to posterior margin; sculpture fine and cancellate, with numerous radial costae crossed by delicate concentric threads. Slit fasciole sulcate, base flat.

Dimensions—Length 10·5; width 6; height 5·25; length of slit 3·5 mm.

Type Locality—Balcombe Bay, Victoria; Balcombian.

Location of Holotype—Dennant Collection, National Museum, Melbourne.

Observations—This species was present in Abattoirs Bore material and compared with authentic specimens from Victoria in the Commonwealth Collection. It has not been recorded elsewhere in South Australia.

Material—3 specimens, Abattoirs Bore.

Stratigraphical Range—? Oligocene-Pliocene.

Geographical Distribution—Gippsland, Vic.; Adelaide, S. Aust.

Emarginula dennanti Chapman & Gabriel

Emarginula dennanti Chapman & Gabriel, 1923. Proc. Roy. Soc. Vic., **36** (n.s.), (1), p. 27, pl. 1, figs. 13, 14; pl. 3, fig. 32.

Emarginula dennanti Chapman & Gabriel. Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 100.
Emarginula dennanti Chapman & Gabriel. Crespin, 1943. Min. Res. Surv. Bull. 9, p. 97.

Diagnosis—Large, elongate-ovate, fairly low, apex about one-third from posterior margin. Sculptured with about 24 primary radial ribs, between which are secondary and fainter tertiary ribs. Radials crossed by undulating and lamellose concentric ridges, producing a tegulate appearance. Slit fasciole sulcate, base flat.

Dimensions—Length 20·5; width 11·75; height 9·75; length of slit 5·25 mm.

Type Locality—Grice's Creek, Victoria.

Location of Holotype—J. F. Bailey Collection.

Material—2 specimens, Abattoirs Bore.

Stratigraphical Range—? Oligocene-Pliocene.

Geographical Distribution—Gippsland, Vic.; Adelaide, S. Aust.

Emarginula dilatoria sp. nov.

pl. 2, fig. 3.

Diagnosis—Shell small, elongate-ovate, apex high, subposterior. Sculpture fine, of 20 primary ribs radiating from apical area, and as many secondary ribs of varying strength, some as strong as the primary ribs near the margin, crossed by concentrics and granulate at intersections. Slit fasciole between 2 sharp ridges, callus formed of concave lamellae.

Description of Holotype—Shell small, thin, fragile, ovate-conical, high. Apex inflated, elevated, strongly incurved, directed posteriorly and situated near posterior margin. Surface convex anteriorly, concave posteriorly. Sculpture of 20 primary radiating riblets from apical area to base, and as many secondary ribs of varying strength, some attaining equal strength with the primaries near the margin. Concentric sculpture less strong than radial, radials gemmulose at junction of concentrics. Slit scarcely differentiated from sculpture, fasciole between 2 sharp ridges, callus formed of concave lamellae, defined internally by a narrow channel with high, smooth, raised edges. Inner margin denticulate at position of rib.

Dimensions—Length (estimated) 6; width 4; height 3 mm.

Type Locality—Hindmarsh Bore, Adelaide, 450-487 feet, Dry Creek Sands

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, F 15144.

Material—Holotype (imperfect); one paratype, broken.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Hindmarsh Bore, Adelaide.

Genus Tugali Gray, 1843.

Tugali Gray, 1843 (in Dieffenbach). Fauna New Zeal., 2, p. 240
(*Tugalia* Gray, 1857 (emend.). Guide Syst. Distr. Moll. Brit. Mus., 1, p. 163)

Type species (monotypy) *Tugali elegans* Gray.

Tugali cicatricosa A. Adams

Tugali cicatricosa A. Adams, 1851. Proc. Zool. Soc., p. 89.
Tugali cicatricosa Adams. Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 100.

Diagnosis—Elongate-ovate, much depressed and expanding posteriorly, narrowing anteriorly, protoconch at about one-quarter from the posterior margin. Lateral margins straight. Surface coarsely decussated with radial riblets and concentric lines. Anterior margin notched.

Dimensions—Length 20; diameter at position of apex 11; apex-posterior margin 4 mm.

Type Locality—Port Lincoln (erroneously ascribed to Philippines in original description and on tablet containing type in British Museum); Recent.

Location of Holotype—British Museum (Natural History).

Observations—The holotype is a young shell, erroneously ascribed to the Philippines. It is identical with examples of the same size from South Australia in the British Museum.

Material—Holotype; 3 examples, Adelaide, S. Aust.; 6 examples, Port Lincoln, S. Aust.

Stratigraphical Range—Dry Creek Sands—Recent.

Geographical Distribution—Victoria and Tasmania to south coast of Western Australia.

Tugali infortunata Ludbrook

Tugali infortunatum Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 82, pl. 4, fig. 1.

Diagnosis—Very small, ovate-oblong, low. Apex at posterior one-quarter. Sculpture of about 40 primary radials with faint secondary radials between. Concentrics fine, numerous, less prominent than radials. Anteriorly sinuate, sinus marked exteriorly by a thickened anterior rib, with a corresponding faint canal within.

Dimensions—Length 4·2; breadth 2·5; height 1·0 mm.

Type Locality—Abattoirs Bore, Adelaide, S. Aust.; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T 1628.

Material—Paratype, Abattoirs Bore; 1 specimen Weymouth's Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Adelaide District.

Tugali nota Cotton

Tugalia nota Cotton, 1947. Rec. S. Aust. Mus., 8, (4), p. 665, pl. 21, figs. 11, 12.

Diagnosis—Large, elongate-ovate, high. Apex at posterior third. Sculpture of about 20 primary radials with 2 or more secondary radials between. Concentric riblets of equal strength, giving fine and regular fenestrate pattern.

Dimensions—Length 19; breadth 11; height 5 mm.

Type Locality—Abattoirs Bore, Adelaide; Dry Creek Sands.

Location of Holotype—S. Aust. Mus. P. 8361.

Material—Holotype.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Abattoirs Bore, Adelaide.

Subfamily Fissurellinae.

Genus Amblychilepas Pilsbry, 1890.

Amblychilepas Pilsbry, 1890. Man. Conch., 12, p. 184.
(*Sophismalepas* Iredale, 1924. Proc. Linn. Soc. N.S.W., 49, (3), 197, p. 219.)

Type species (o.d.) *Fissurella trapezina* Sowerby = *F. javanicensis* Lamarck.

Amblychilepas aera (Cotton)

Sophismalepas nigrita Sowerby; Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 100.
Sophismalepas aera Cotton, 1947. Rec. S. Aust. Mus., 8, (4), p. 665, pl. 20, figs. 4, 5.

Diagnosis—Elongate-ovate, sides not parallel but converging somewhat anteriorly. Shell fairly high near dorsal orifice, but depressed towards margin; elevated at each end. Sculpture of numerous fine bifurcating radial threads. Orifice one-quarter length of shell.

Dimensions—Length 14; breadth 9; height 3 mm.

Type Locality—Salisbury Bore, 330 feet; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T 1729.

Observations—The Recent species, *nigrita* Sowerby, has been recorded (Chapman & Gabriel, 1923, p. 37) from the Miocene of the Murray Cliffs near Morgan and the Kalimnan of Muddy Creek, Victoria. The latter occurrence is here confirmed from examination of specimens in the British Museum. Dry Creek Sands examples are not *nigrita*, although they were formerly identi-

fied as such. Compared with type material of *nigrita* in the British Museum, the present species is more elevated in the centre towards the dorsal aperture, and more flattened to concave towards the margin. The sides are not parallel. The sculpture is of bifurcating threads rather than intercalating riblets. The interior of the apertural margin in the Hindmarsh Bore specimen (a young shell) is not thickened and is inclined to be frilled. Compared with *nigrita*, the dorsal aperture is smaller in relation to the total length; in *nigrita* it is 1 : 3, in *acra* 1 : between 4 and 5.

In introducing the generic name *Sophismalepas* for *nigrita*, Iredale (1924, p. 219) has drawn distinction between his genus and both *Lucapinella* and *Megatebennus*. He does not give any diagnostic difference between *Sophismalepas* and *Amblychilepas*, proposed by Pilsbry as a section of *Megatebennus* with the Australian shell *javanicensis* Lamarck as type species, and including *nigrita*. As there is no recognizable generic difference between *nigrita* and *javanicensis*, *Sophismalepas* must be regarded as a synonym of *Amblychilepas*.

Cotton & Godfrey (1934, pp. 47-50) have used *Amblychilepas* for *javanicensis* and *omicron* and *Sophismalepas* for *nigrita* and *oblonga*, quoting Iredale to differentiate the genus *Sophismalepas*. According to the definitions they give of the two "genera" the only difference between them is that *Amblychilepas* is saddle-shaped and *Sophismalepas* oblong-oval. This can hardly be a generic feature as the ratio length-breadth of the 4 species can be arranged in series. In *javanicensis* the ratio is 1·25; in *omicron* 1·3; in *nigrita* 1·47; in *oblonga* 2·0. The present species, *acra*, with ratio 1·56 is a further link in the series. The shape must, therefore, be disregarded as diagnostic, particularly in view of the fact that *nigrita* is closer in the series to *javanicensis* than it is to *oblonga*.

Material—Specimen from Hindmarsh Bore, 450-487 feet.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Adelaide District, S. Aust.

Family TROCHIDAE.[1]

Subfamily MARGARITINAE.

Genus EUCHELUS Philippi, 1847.

Euchelus Philippi, 1847. Zeitsch. f. Malakozool., Feb., p. 20.

Type species (s.d. Herrmannsen, 1847) *Trochus quadricarinatus* Chemnitz = *atratus* Gmelin.

Subgenus HERPETOPOMA Pilsbry, 1889.

Herpetopoma Pilsbry, 1889, in Tryon, Man. Conch., 11, p. 430.

Type species (o.d.) *Euchelus scabriusculus* Adams & Angas.

Euchelus (Herpetopoma) pliocenicus (Ludbrook)

Euchelus baccatus Chapman & Gabriel, 1914 (non Menke). Proc. Roy. Soc. Vic., 26 (n.s.), (2), p. 316.

Herpetopoma pliocenica Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 87, pl. 4, fig. 18.

Diagnosis—Small, thin, protoconch of 1½ flatly convex axially lirate turns, adult whorls 4, sculptured with equidistant, granulose, spirals, increasing by intercalation from 5 on the post-embryonic whorl to 9 on the penultimate whorl; 13 on body whorl from suture to umbilicus. Interspaces wider than ribs, with fine, regular axial threads.

Dimensions—Height 9; diameter 7 mm.

Type Locality—Abattoirs Bore, Adelaide; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T1641.

Material—8 paratypes, Abattoirs Bore; 3 specimens, Weymouth's Bore; 2 broken specimens, Hindmarsh Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Adelaide District.

[1] Most of the species in this family were figured in 1941, this Journal, 65, (1), pls. 4, 5.

Subfamily CALLIOSTOMINAE.

Genus CALLIOSTOMA Swainson, 1840.

Calliostoma Swainson, 1840. Treat. Malac., p. 351.
Calliostoma Swainson. Wenz, 1938. Handb. Pal. Gast. 2, p. 281 (synonymy).

Type species (s.d. Herrmannsen, 1846) *Trochus conulus* Linné.

Subgenus LAETIFAUTOR Iredale, 1929.

Laetifautor Iredale, 1929. Mem. Qld. Mus., 9, (3), p. 271.

Type species (o.d.) *Calliostoma trepidum* Hedley = *deceptum* Smith.

Calliostoma (Laetifautor) obliquicancellatum (Ludbrook)

Laetifautor obliquicancellatus Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 84, pl. 4, fig. 7.

Diagnosis—Protoconch smooth, high, of one-and-a-half turns. Whorls flat, periphery angular. Sculpture fairly regular, of 5 to 7 strong, granulate lirae per whorl, crossed by equal, sharp axial ridges, producing an obliquely rhombic cancellation with granules at the intersections. Base flat with 10 granular spirals and close radials.

Dimensions—Height (estimated) 8; diameter 6 mm.

Type Locality—Abattoirs Bore, Adelaide; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T1658.

Observations—Hypotype from Weymouth's Bore has the early whorls complete; the protoconch is elevated and small, of one-and-a-half turns.

Material—6 paratypes (broken). Abattoirs Bore; 1 hypotype, Weymouth's Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Adelaide District, S. Aust.

Calliostoma (Laetifautor) spinicarinatum (Ludbrook)

Laetifautor spinicarinatus Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 84, pl. 4, fig. 8.

Diagnosis—Broadly conical; 4 adult whorls slightly concave, anteriorly carinate. Three strong spiral lirae on the posterior half of the whorl, two keels on the anterior half, each surmounted by two or three crowded lirae, those on the keel, nearer the suture, equal, those on the further keel unequal, keel nearer suture weaker than further keel.

Spirals crossed by oblique axials; intersections sharply granulose.

Dimensions—Height 5·5; diameter 4·8 mm.

Type Locality—Abattoirs Bore, Adelaide; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T1652.

Material—7 paratypes.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Abattoirs Bore, Adelaide.

Calliostoma (Laetifautor) crebrinodulosum (Ludbrook)

Laetifautor crebrinodulosus Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 85, pl. 4, fig. 9.

Diagnosis—Small, conical, rather high, stout. Adult whorls 6, slightly convex, sculptured with strong spirals increasing by intercalation to four primary and three secondary on the body whorl crossed by regular oblique axials, 20 on the penultimate whorl. Granular at intersections. Base convex, with seven spirals equal to interspaces, crossed by numerous fine radials.

Dimensions—Height 7·9; diameter 6 mm.

Type Locality—Abattoirs Bore, Adelaide; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T1653.

Material—Holotype; 1 paratype.

Stratigraphical Range—Dry Creek Sands.
Geographical Distribution—Abattoirs Bore, Adelaide.

Calliostoma (Laetifautor) bicarinatum (Ludbrook)

Laetifautor bicarinatus Ludbrook, 1941. Trans. Roy. Soc. S. Aust. 65, (1), p. 85, pl. 4, fig. 13.
Laetifautor bicarinatus Ludbrook. Crespin, 1943. Min. Res. Surv. Bull. 9, p. 97.

Diagnosis—Small, falsely perforate. Protoconch very small, adult whorls 6, with a strong peripheral cord above the suture supporting 4 beaded lirae; above this a narrow beaded cord and then 4 strong beaded lirae on the posterior portion of the whorl. Oblique axial lirae in early whorls, becoming obsolete in penultimate and body whorls. Base flat, with 8 equal spiral lirae equal to the interspaces.

Dimensions—Height 6·5; diameter 4·8 mm.

Type Locality—Abattoirs Bore, Adelaide; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T1632.

Observations—This is the most common species of the subgenus *Laetifautor* in the Dry Creek Sands. It has also been recorded (Crespin, 1943, p. 97) from the Kalimnan of Gippsland.

Material—9 paratypes, Abattoirs Bore; 5 specimens, Weymouth's Bore; 7 specimens, Hindmarsh Bore.

Stratigraphical Range—Kalimnan-Dry Creek Sands.

Geographical Distribution—Gippsland, Vic.; Adelaide, S. Aust.

Genus ASTELE Swainson, 1855.

Astele Swainson, 1855. Proc. Roy. Soc. Tas. 3, (1), p. 38.

Type species (monotypy) *Astele subcarinatum* Swainson.

Subgenus ASTELE s. str.

Astele (Astele) fanaticum Ludbrook

Astele fanaticum Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 86, pl. 4, fig. 6.

Diagnosis—Depressed conical, whorls sloping and angular, somewhat concave. Adult whorls three, flattened beneath the suture in an almost horizontal narrow plane, then steeply sloping for the rest of the whorl. Periphery carinate. Sculpture of fine, equal spiral threads, four on the infra-sutural plane, nine on the oblique portion of the whorl, 14 on the base of the body whorl. Interstices with very fine axial threads.

Dimensions—Height 6·1; diameter 7·0 mm.

Type Locality—Abattoirs Bore, Adelaide; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T1650.

Material—Holotype T1650, 4 paratypes and 3 fragments, Abattoirs Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Abattoirs Bore, Adelaide, S. Aust.

Subgenus PULCHRASTELE Iredale, 1929.

Pulchrastele Iredale, 1929. Mem. Qld. Mus., 9, (3), p. 271.

Type species (o.d.) *Astele septenarium* Melvill & Standen.

Astele (Pulchrastele) planiconicum (Ludbrook)

Pulchrastele planiconicum Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 86, pl. 5, fig. 12.

Diagnosis—Narrowly conical, whorls flattened. Protoconch of two turns; six adult whorls each bearing above the suture a strong peripheral cord supporting beaded lirae increasing to five on the cord of the body whorl. Above the cord lirae increasing by intercalation to five on the body whorl. Spirals crossed by numerous strong axials. Base with 11 primary and one or two faint secondary spirals, granulose near the umbilicus, and numerous faint radials.

Dimensions—Height 8; diameter 5·5 mm.
Type Locality—Abattoirs Bore, Adelaide; Dry Creek Sands.
Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T1660.
Material—Holotype.
Stratigraphical Range—Dry Creek Sands.
Geographical Distribution—Abattoirs Bore, Adelaide, S. Aust.

Astele (Pulchrastele) tuberculatum (Ludbrook)

Pulchrastele tuberculatum Ludbrook, 1941. Trans. Roy. Soc. S. Aust., **65**, (1), p. 80, pl. 4, fig. 15.

Diagnosis—Broadly conical. Protoconch very small, flattened, of one-and-a-half turns; adult whorls five, with a thick cord supporting four small tuberculate lirae at the periphery. Tubercles continuous over the cord. Three narrow spirals with small prominent tubercles above the cord. Aperture small, rhombic. Base flat with eight strong spirals, the umbilical of which are tuberculate.
Dimensions—Height 4·8; diameter 4·5 mm.
Type Locality—Abattoirs Bore, Adelaide; Dry Creek Sands.
Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T1636.
Material—Five paratypes, several fragments, Abattoirs Bore.
Stratigraphical Range—Dry Creek Sands.
Geographical Distribution—Abattoirs Bore, Adelaide.

Subfamily Monodontinae.

Genus Cantharidus Montfort, 1810.

Cantharidus Montfort, 1810. Conch. Syst., 2, p. 250.
Cantharidus Montfort. Wenz, 1938. Handb. Pal. Gast., 2, p. 302 (synonymy).

Type species (monotypy) *Cantharidus iris* = *Trochus iris* Gmelin.

Subgenus Phasianotrochus P. Fischer, 1885.

Phasianotrochus P. Fischer, 1885. Man. de Conch., p. 819.

Type species (monotypy) *Trochus badius* Wood.

Cantharidus (Phasianotrochus) laxegemmatus (Ludbrook)

Phasianotrochus laxegemmatus Ludbrook, 1941. Trans. Roy. Soc. S. Aust., **65**, (1), p. 83, pl. 4, fig. 4.

Diagnosis—Very small, acutely conical at apex, protoconch of one-and-a-half convex turns. Adult whorls with a strong peripheral lirate cord above the suture with prominent, widely spaced tubercles. Five equal spiral lirae, broader than interstices, above the cord crossed by numerous crowded axials. Base convex with 11 equal spiral lirae and numerous radial striae.
Dimensions—Height 4·6; diameter 3·7 mm.
Type Locality—Abattoirs Bore, Adelaide; Dry Creek Sands.
Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T1662.
Material—11 paratypes, Abattoirs Bore; two examples, Weymouth's Bore.
Stratigraphical Range—Dry Creek Sands.
Geographical Distribution—Abattoirs and Weymouth's Bores, Adelaide.

Cantharidus (Phasianotrochus) subsimplex (Ludbrook)

Phasianotrochus subsimplex Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 83, pl. 4, fig. 10.

Diagnosis—Small, thin, narrowly conical, protoconch flattened, of two-and-a-half turns; whorls only slightly convex, suture linear. Sculpture fine, of numerous crowded microscopic spiral and oblique axial striae. Base slightly convex, with 12 spiral striae and faint oblique axials.
Dimensions—Height 4·8; diameter 3·7 mm.
Type Locality—Abattoirs Bore, Adelaide; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T1663.

Material—Eight paratypes, Abattoirs Bore; two examples, Hindmarsh Bore; two examples, Weymouth's Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Adelaide District, S. Aust.

Genus THALOTIA Gray, 1847.

Thalotia Gray, 1847. Proc. Zool. Soc., 15, p. 145.

Type species (e.d.) *Trochus pictus* W. Wood = *Monodonta conica* Gray.

Subgenus CALTHALOTIA Iredale, 1929.

Calthalotia Iredale, 1929. Mem. Qld. Mus., 9, (3), p. 271.

Type species (e.d.) *Trochus arruensis* Watson.

Thalotia (Calthalotia) nitidissima (Ludbrook)

Calthalotia nitidissima Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 83, pl. 4, fig. 11.

Diagnosis—Small but solid, imperforate, conical. Adult whorls five, with strong, even granulose spirals increasing from three on the first to seven on the body whorl. Interstices with oblique axial lirae increasing in number towards the last whorl. Oblique cancellation in the early whorls, strong and regular granulation on the body whorl. Base convex, with nine narrow, slightly granulose spirals and numerous axials. Columella slightly curved, with a slight callus.

Dimensions—Height 6; diameter 5 mm.

Type Locality—Abattoirs Bore, Adelaide; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T1661.

Observations—This species is very close to the type species of the subgenus *T.* (*C.*) *arruensis* Watson. *Nitidissima* lacks the cord above the suture and its gemmulate lirae are more uniform than in *arruensis*.

Material—Four paratypes, Abattoirs Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Abattoirs Bore, Adelaide.

Thalotia (Calthalotia) fictilis (Ludbrook)

Calthalotia fictilis Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 84, pl. 4, fig. 14.

Diagnosis—Small and fairly thin, falsely perforate. Adult whorls 4, sculptured with fine subequal spiral lirae, 8 on the body whorl, reticulated by numerous, fine oblique axials of about half the strength of the spirals. Base convex, with 8 smooth spirals crossed by minute accremental striae. Periphery angulate; columella arcuate.

Dimensions—Height 4·0; diameter 3·5 mm.

Type Locality—Abattoirs Bore, Adelaide; Dry Creek Sands.

Location of Holotype—Tate Mus. Col., Univ. of Adelaide, T1624.

Material—10 paratypes and broken specimens, Abattoirs Bore; 6 specimens, Weymouth's Bore; 4 specimens, Hindmarsh Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Adelaide District.

Subfamily TROCHINAE.

Genus CLANCULUS Montfort, 1810.

Clanculus Montfort, 1810. Conch. Syst., 2, p. 190.

Clanculus Montfort. Wenz, 1938. Handb. Pal., Gast., 2, p. 313 (synonymy).

Type species (monotypy) *Trochus pharaonius* Linné.

Subgenus EURICLANCULUS Cotton & Godfrey, 1934.

Euriclanculus Cotton & Godfrey, 1934. S. Aust. Nat., 15, (3), p. 78.

Type species (e.d.) *Clanculus flagellatus* Philippi.

Clanculus (Euriclanculus) quadricingulatus Ludbrook

Clanculus quadricingulatus Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 82, pl. 4, fig. 2.

Diagnosis—A *Clanculus* (*Euriclanculus*) with 4 adult whorls, sculptured with granulose cinguli, four on the penultimate whorl, 13 from the suture to the umbilical fissure on the body whorl, the nine on the base finer, more closely granulose and more closely set than the four above the periphery. Granulation develops progressively from smooth cinguli on neanic whorls to coarse granulation on body and penultimate whorls. Suture depressed; periphery rounded.

Dimensions—Height 6·2; diameter 6·9 mm.

Type Locality—Abattoirs Bore; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T1623.

Observations—This and the species *eucarinatus* belong to the subgenus *Euriclanculus*, which is very close to *Clanculus* s. str. in its umbilical and apertural characters. The two Pliocene species are closest to *C. ceylonicus* G. & H. Nevill from Ceylon. They are of the same size as that species and the ornament is similar. Most present day species of *Clanculus* in southern Australia are larger.

Material—2 paratypes, Abattoirs Bore; 5 examples, Hindmarsh Bore; 2 examples, Weymouth's Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Adelaide District.

Clanculus (Euriclanculus) eucarinatus Ludbrook

Clanculus eucarinatus Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 83, pl. 4, fig. 3.

Diagnosis—*Clanculus* with 4 adult whorls bearing 4 granulose cinguli, 3 equal in size, the fourth a strong peripheral cord. Suture deeply canaliculate. Interstices between the cinguli axially lirate, three lirae corresponding to two granules on the cinguli. Periphery roundly carinate, base convex with 9 fine granulose cinguli and axially lirate interstices.

Dimensions—Height 5·2; diameter 5·6 mm.

Type Locality—Abattoirs Bore, Adelaide; Dry Creek Sands.

Location of Types—Tate Mus. Coll., Univ. of Adelaide, T1647.

Material—3 paratypes, Abattoirs Bore; 1 specimen, Hindmarsh Bore; 6 specimens, Weymouth's Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Adelaide District.

Subfamily UMBONIINAE

Genus ISANDA A. Adams, 1854

Isanda A. Adams, 1854. Gen. Rec. Moll., 1, p. 409.

Type species (o.d.) *I. coronata* A. Adams.

Subgenus MINOLIA A. Adams, 1860.

Minolia A. Adams, 1860. Ann. Mag. Nat. Hist., ser. 3, 6, p. 336.
Minolia Adams. Wenz. 1938. Handb. Pal. Gast., 2, p. 317.

Type species (monotypy) *Minolia punctata* A. Adams.

Isanda (Minolia) perglobosa (Ludbrook)

Ethminolia perglobosa Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 86, pl. 4, fig. 5.

Diagnosis—Protoconch flattened, of 3 very small turns; 3 adult whorls convex, with numerous fine spiral striae crossed irregularly and frequently by faint, oblique, axial striae. Periphery rounded, but with a strong tendency to angulation. Base convex.

Dimensions—Height 4·6; diameter 5·8 mm.

Type Locality—Abattoirs Bore; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T1640.

Observations—Although this species was described originally in *Ethminolia* the writer now considers that it more properly belongs to *Minolia*. It is very closely related to *Minolia pulcherrima* Angas, retained by Iredale in *Minolia*, and lacks the medial angulation said to be diagnostic of *Ethminolia*. Wenz (1938, p. 317) has synonymized *Ethminolia* with *Minolia*.

Material—17 paratypes, Abattoirs Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Abattoirs Bore, Adelaide.

Genus Spectamen Iredale, 1924.

Spectamen Iredale, 1924. Proc. Linn. Soc. N.S.W., 49, (3), p. 227.

Type species (o.d.) *Trochus philippensis* Watson.

Spectamen planicarinatum sp. nov.

pl. 2, fig. 4.

Solariella strigata Tenison-Woods sp. Harris, 1897. Cat. Tert. Moll. Brit. Mus., 1, p. 285 (in part No. 4173).

Solariella strigata (T.-Woods). Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 100 (in part).

Diagnosis—Depressed and broadly conical, very small, thin, perforate. Spire whorls carinate, flattened and generally horizontal posteriorly between the suture and the first carina, flat area relatively smooth with fine spiral threads and faint, oblique growth-lines only. Whorl abruptly and flatly descending anteriorly. On this area about 3 conspicuous and evenly spaced lirae. Body whorl relatively large with the posterior carina and a carina at the periphery. Flat area between the suture and the posterior carinae as on the spire whorls, between the 2 carinae sculpture of equal of subequal lirae. Base convex with fine spiral striae between the peripheral carina and the umbilicus. Umbilicus spirally and longitudinally lineate; bordered by a conspicuous keel.

Description of Holotype—Shell very small, turbinate, depressed and broadly conical. Protoconch small, sharply elevated, of two-and-a-half smooth turns, adult whorls three, flattened posteriorly between the suture and carina, posterior area relatively smooth with fine spiral threads and oblique axial growth-lines only. Whorl descending obliquely anterior to the carina, sculptured with three evenly spaced lirae. Body whorl relatively large, with the posterior carina and a second carina at the periphery. Subsutural flat area with fine spiral threads and oblique growth axials only; area between the carinae with three evenly spaced lirae. Base convex, with fine spiral striae between the peripheral carina and the umbilicus. Umbilicus very wide, spirally and longitudinally lineate, bordered by a conspicuous keel. Aperture subquadrate, interrupted by previous whorl.

Dimensions—Height 2·4; diameter 4 mm.

Type Locality—Abattoirs Bore; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, F15145.

Observations—*Solariella strigata* has hitherto been regarded as a somewhat variable species and Dry Creek Sands examples have been specifically compared with Miocene variants. Among material in the British Museum, classified as *S. strigata*, three distinct species may be recognized; first, *strigata* with its crenulate carina and crenulate umbilical margin; secondly, the small species described above with a flat, almost smooth horizontal posterior area and no crenulations on the carinae; and thirdly, one example of the species *praecursor* described below, similar in size to *strigata* but differing in sculpture.

S. strigata does not occur in the Dry Creek Sands, but the other two species are well represented.

The genus *Spectamen* to which all three species belong, *strigata* having previously been considered ancestral to the *Spectamen philippense* series in

New South Wales (Iredale, 1929c, p. 167), is by Wenz (1938, p. 274) placed in synonymy with *Solariella*. The type species of *Solariella, S. maculata* Wood, from the Pliocene Crag, is generically different from *Spectamen*. In *Solariella* the area below the suture is excavate, not flat to convex. The sculpture is of strong gemmulate spiral cords, 3 per whorl in the type species, the apex is flattened, the umbilicus is strongly gemmulate and longitudinally lirate; the base is strongly corded. In *Spectamen* the whorls are not strongly corded but lirate, the area below the suture is flat to convex with oblique axial growth striae; there may be some gemmulation of the carina bordering the flat area; the base is convex and generally smooth but for fine threads or lirae; the umbilicus is weakly crenulate to practically smooth.

The genus *Spectamen* appears to belong to the Indo-Pacific and Australian regions, the two Tertiary species, *planicarinatum* and *praecursor*, being more closely related to Indian Ocean species than to Australian. The nearest living ally of *planicarinatum* is "*Solariella*" *biangulosa* A. Adams from the West Coast of India, a flattish species with a flat area beneath the suture, and two keels. "*Solariella*" *biangulosa* should also be placed in *Spectamen*. The Miocene *strigata* with its somewhat gemmulate carina and umbilicus is more closely allied to *Spectamen* than to *Solariella*.

Material—Holotype, 3 paratypes, Abattoirs Bore; numerous paratypes, Hindmarsh Bore; 6 paratypes, Weymouth's Bore; 3 paratypes, Lower Beds Muddy Creek, Victoria, B.M. Coll.

Stratigraphical Range—Miocene-Dry Creek Sands.

Geographical Distribution—Muddy Creek, Vic.; Adelaide, S. Aust.

Spectamen praecursor sp. nov.

pl. 2, fig. 5.

Solariella strigata Tenison-Woods sp. Harris, 1897. Cat. Tert. Moll. Brit. Mus., 1, p. 283 (No. 9168 in part).

Solariella strigata (T. Woods). Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 100 (in part).

Diagnosis—Small, conical, thin; protoconch of 3 small and smooth turns. Whorls flattened but oblique beneath suture, elsewhere convex. Sculptured over whole whorl with spiral lirae, about 5 on flat posterior area and 4 primaries with from 2 to 5 secondaries between on the convex portion above the shoulder on the body whorl. Base slightly convex, with 5 primary and 5 secondary lirae. Umbilicus axially and spirally lirate, bordered by a moderate cord.

Description of Holotype—Shell small, conical, thin, turbinate, apical angle about 75 deg. Protoconch small and sharp of 3 smooth turns, adult whorls 4 flattened posteriorly below the linear suture; flattened area sculptured with fine spiral lirae increasing by intercalation to 5 near the aperture on the body whorl, and crowded fine equidistant oblique axials. Whorl convex between posterior area and shoulder sculptured also with fine lirae increasing by intercalation to 4 primaries with from 2 to 5 secondaries between. Shoulder carinate, base slightly convex with 5 primary spirals and intermediate secondary spirals. Axials less prominent than on posterior flat area. There is a tendency to obsolete plication of the whorls with resultant gemmulation of the spirals, visible only in oblique light. Umbilicus widely open, spirally and axially lirate within, bordered by a moderate cord, somewhat gemmulate where it is crossed by the axials. Aperture subquadrate, interrupted by the previous whorl.

Dimensions—Height 5; diameter 5·5 mm.

Type Locality—Weymouth's Bore, 310-330 feet; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, F15146.

Observations—From the previous species, *S. planicarinatum, S. praecursor* may be distinguished by its higher spire and less flattened whorls. The flat area beneath the suture is narrower, oblique and more strongly sculptured. The

nearest living species is "*Solariella*" *sayademalha* Melvill from the Saya de Malha Banks, Indian Ocean, which should also be placed in *Spectamen*. In the Recent species the radial threads on the flat subsutural area are stronger and the spiral lirae are weaker. Otherwise the two species are very alike, even as to size.

Material—Holotype, 7 complete and 5 broken paratypes, Weymouth's Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Weymouth's Bore, Adelaide.

Family STOMATIIDAE.
Subfamily STOMATIINAE.
Genus GENA S. Adams, 1850.

Gena Adams, 1850. Proc. Zool. Soc., p. 36.

Type species (s.d. Fischer, 1885) *Stomatella planulata* Lamarck.

Gena incola Cotton

Gena sp. Ludbrook, 1941. Trans. Roy. Soc. S. Aust., **65**, (1), p. 100.
Gena incola Cotton, 1947. Rec. S. Aust. Mus., **8**, (4), p. 666, pl. 21, figs. 13, 14.

Diagnosis—Small, flat, narrowly elongate, aperture very large, about four-fifths longest diameter of shell. Protoconch smooth, shining, adult whorls microscopically sculptured with very fine spiral striae and curved axials of growth.

Dimensions—Height 3; diameters 10 and 16 mm.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T1731.

Observations—The authorship and designation of the genus *Gena* is complex. The name was introduced by Gray in 1840 as a nomen nudum in the Synopsis of the Contents of the British Museum, ed. 12, p. 147. In 1847, *Gena* was included by Gray in his List of the Genera of Recent Mollusca, P.Z.S., p. 146, *Patella lutea* of Linné being cited as type. The genus was first defined by Adams in 1850 (P.Z.S., p. 36) and the species listed. "*Patella lutea*" was not included; the first species cited was *Stomatella planulata* Lamarck. Subsequently, in 1854 (Thes. Conch. 2, p. 828), Adams described a *Gena lutea* considered by him to be equivalent to Linné's *Patella lutea* with which he made *Stomatella auricula* of Lamarck synonymous.

Hanley, however (1855, p. 424), considered that *Patella lutea* of Linné was unrecognizable, and probably not the equivalent of Adams's *Gena lutea*.

This view was accepted by Pilsbry in 1890, *Stomatella planulata* being cited as type. Fischer had, however, already cited *planulata* as the type of *Gena* in 1885.

There appears at the time of writing to be no ruling of the International Committee on the validity of a genus based on a doubtful species. The first valid use of the name therefore appears to be that of Adams in 1850 with subsequent designation by Fischer in 1885.

Material—1 specimen (juvenile), Abattoirs Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Adelaide District.

Family SKENEIDAE.
Genus TEINOSTOMA H. & A. Adams, 1853.

Teinostoma H. & A. Adams, 1853. Gen. Rec. Moll., 1, p. 122.
(*Tinostoma* P. Fischer, 1885. Man. de Conch., p. 834.)

Type species (s.d. Cossmann, 1888) *Teinostoma politum* A. Adams.

Teinostoma depressulum Chapman & Gabriel
pl. 2, fig. 13.

Teinostoma depressula Chapman & Gabriel, 1914. Rec. Geol. Surv. Vic., **26** (n.s.) (2), p. 317, pl. 27, figs. 24a, b.
Teinostoma depressula Chapman & Gabriel, Ludbrook, 1941. Trans. Roy. Soc. S. Aust., **65**, (1).

Diagnosis—Very small, solid, smooth, depressed, apical surface smooth. Umbilical area sunken, filled with callus. Aperture subovate, lip produced posteriorly; excavate below.

Dimensions—Height 0·75; diameter 1·84 mm.

Type Locality—Bore 10, 225-230 feet, near Ouyen, Mallee District, Victoria.

Location of Holotype—Geol. Surv., Vic. Coll., Melbourne.

Observations—*T. depressulum* is a typical *Teinostoma*, resembling the small species *T. rotellaeforme*, *T. complanatum* and *T. dubium* from the Parisian Eocene. The Recent type species, *T. politum*, is considerably larger.

Material—8 specimens, Abattoirs Bore; 22 specimens, Hindmarsh Bore; 10 specimens, Weymouth's Bore.

Stratigraphical Range—Kalimnan-Dry Creek Sands.

Geographical Distribution—Gippsland, Vic.; Adelaide, S. Aust.

Genus Starkeyna Iredale, 1930.

Stipator Iredale, 1924. Proc. Linn. Soc. N.S.W., 49, (3), 197, p. 233 (non Rehn, 1900).
Starkeyna Iredale, 1930. Aust. Zool., 6, p. 175 (nom. nov. for *Stipator* preocc.).

Type species (monotypy) *Teinostoma starkeyae* Hedley.

Starkeyna pulcherrima (Chapman & Gabriel)

pl. 2, fig. 17.

Teinostoma pulcherrima Chapman & Gabriel, 1914. Proc. Roy. Soc. Vic., 26 (n.s.), (2), p. 317, pl. 27, figs. 26a-c.

Diagnosis—Spire flattened, whorls flatly convex, protoconch small of 2½ turns, adult whorls 3. Suture linear. Base flattish, umbilicus partly filled with callus which extends about halfway over the surface of the base of the body whorl. Aperture subquadrate, slightly notched posteriorly. Produced posteriorly and excavate below.

Dimensions—Height 1·75; diameter 4·75 mm.

Type Locality—Bore 10, 225-230 feet, near Ouyen, Mallee Bore District, Victoria.

Location of Holotype—Geol. Surv. Vic. Coll., Melbourne.

Observations—This species previously known only from the Kalimnan of the Mallee Bores was considered by Chapman and Gabriel as a "variant" of *Teinostoma*, perhaps referable to *Bonnetella* (= *Bonnetia* Cossmann non Robineau-Desvoidy, 1830) of Cossmann. It is not a *Teinostoma*, lacking the completely closed umbilicus and the obscured spire; *pulcherrima* has the umbilicus only partly filled, the callus spreading in a band over about half the base. The spire is naticoid and the suture linear. The species is placed in Iredale's *Starkeyna*, created for *Teinostoma starkeyae* Hedley, to which it appears to bear the closest resemblance. It is not congeneric with *Bonnetia planispira* Cossmann, the type species of *Bonnetella*.

Material—17 specimens, Abattoirs Bore.

Stratigraphical Range—Kalimnan-Dry Creek Sands.

Geographical Distribution—Western Victoria; Adelaide, S. Australia.

Genus Tubiola A. Adams, 1863.

Tubiola A. Adams, 1863. Proc. Zool. Soc., p. 74.

Type species (s.d. Kobelt, 1878) *T. nivea* A. Adams.

Subgenus Partubiola Iredale, 1936.

Partubiola Iredale, 1936. Rec. Aust. Mus., 19, (5), p. 280.

Type species (monotypy) *Partubiola blancha* Iredale.

Tubiola (Partubiola) depressispira (Ludbrook)

Partubiola depressispira Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 87, pl. 4 fig. 16.

Diagnosis—Whorls tricarinate, at first more or less rounded then with 3 regularly disposed carinae with flattened areas between. Subsutural area decidedly sunken. About 6 spiral lirae between each pair of keels. Faint axials reticulating the spirals on the whorls more prominent on the base. Base flattened near carina, convex toward the umbilicus. Aperture roundly quadrate, outer lip attached to previous whorl at median carina.

Dimensions—Height 1·5; diameter 3·5 mm.

Type Locality—Abattoirs Bore, Adelaide; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T1649.

Observations—The subgenus *Partubiola* is well represented in the Indo-Pacific fauna by a group including "*Cyclostrema*" *carinatum* H. Adams, *quinquecarinatum* and *novemcarinatum* Melvill, all very small species like the type species *blancha* Iredale. *Tubiola nivea*, the type species of *Tubiola* is a comparatively large shell, less carinate and less flattened than those of the subgenus *Partubiola*.

Material—19 paratypes, Abattoirs Bore; 3 specimens, Weymouth's Bore; 7 specimens, Hindmarsh Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Adelaide District.

Tubiola (Partubiola) varilirata (Ludbrook)

Partubiola varilirata Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 87, pl. 4, fig. 17.

Diagnosis—Whorls with one carina at the posterior one-third of the whorl. Whorl above the carina flat, depressed with about 8 very fine lirae; below the carina convex with stronger and more widely separated lirae. About 13 strong, subequal lirae on the body whorl between the carina and umbilicus.

Dimensions—Height 1·3; diameter 3·5 mm.

Type Locality—Abattoirs Bore; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T1631.

Material—10 paratypes, Abattoirs Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Abattoirs Bore, Adelaide.

Genus Crossea A. Adams, 1865.

Crossea A. Adams, 1865. Ann. Mag. Nat. Hist., Ser. 3, 15, p. 323.
(*Crosseia* Fischer, 1885. Man. de Conch., p. 778.)

Type species (s.d. Fischer, 1885) *C. miranda* A. Adams.

Subgenus Dolicrossea Iredale, 1924.

Dolicrossea Iredale, 1924. Proc. Linn. Soc. N.S.W., 49, (3), 197, p. 251.

Type species (o.d.) *Crossea labiata* Tenison-Woods.

Crossea (Dolicrossea) cf. labiata Tenison-Woods

Crossea labiata Tenison-Woods, 1876b. Proc. Roy. Soc. Tas. for 1875, p. 151.
Dolicrossea labiata Tenison-Woods. Iredale, 1924. Proc. Linn. Soc. N.S.W., 49, (3), 197, p. 251.
Dolicrossea labiata (Tenison-Woods). Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 88.

Diagnosis—Spire elevated, suture impressed, whorls very finely, spirally, lirate and axially striate. Umbilicus bordered with a callus; aperture ovate, both anteriorly and posteriorly angulate and channelled. Outer lip variced.

Dimensions—Height 4; diameter 2 mm.

Type Locality—Long Bay, Tasmania, 10 fathoms; Recent.

Location of Holotype—? Hobart Museum.

Observations—No further material has become available since that of the Abattoirs Bore and the fossil species is still tentatively referred to *labiata* in the absence of complete specimens with unbroken outer lip.

Wenz (1938, p. 333) has placed Iredale's *Dolicrossea* in synonymy with *Crossea*; in erecting the genus Iredale did not define the characters which separate it from *Crossea*. The type species of *Crossea*, *C. miranda*, has several strong varices which do not occur on any other species of the genus that the writer has seen. The genus as a whole is readily divisible into sections, on the varices, as shown by Tate (1890, p. 220). *Crossea* s. str. is strongly variced. *Dolicrossea* has a variced outer lip, while *Crosseola* has a simple lip, the whorls being either cancellate or punctate. The fossil specimens under present consideration all have the outer lip broken so that even subgeneric location is tentative: the absence of cancellate or punctate sculpture is suggestive of *Dolicrossea*, which is retained as the subgenus.

Material—5 specimens, Abattoirs Bore; 9 specimens, Recent, Tasmania (B.M. Coll.).

Stratigraphical Range—Dry Creek Sands-Recent.

Geographical Distribution—Southern Australia.

Family TURBINIDAE.

Subfamily Liotiinae.

Genus Liotina Munier-Chalmas, 1885.

Liotina Munier-Chalmas in Fischer, 1885. Man. de Conch., p. 831.

Type species (o.d.) *Delphinula gervillei* Defrance.

Subgenus Munditia Finlay, 1927.

Munditia Finlay, 1927. Trans. N.Z. Inst., 57, p. 363.

Type species (o.d.) *Liotina tryphenensis* Powell.

Liotina (Munditia) tasmanica (Tenison-Woods)

pl. 2, fig. 6.

Liotina lamellosa, T. Woods. Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 100.
Liotella capitata Hedley. Ludbrook, 1941, ibid.

Diagnosis—Shell flatly depressed, bicarinate, sculptured with distant spiral ribs crossed by equal radial ribs, intersections nodulose. Interspaces crowded with fine close imbricating lamellae. Umbilicus widely open, spirally lamellose.

Dimensions—Height 3; diameter major 8; diameter minor 6 mm.

Type Locality—Long Bay, Tasmania.

Location of Holotype—Hobart Museum.

Observations—The small shells from the Abattoirs Bore previously identified with *Liotina lamellosa* (= *L. roblini* Johnston) are not *lamellosa*, which has a more elevated spire, but *tasmanica*, and are conspecific with Recent specimens so identified in the British Museum. Recent adult *tasmanica* are larger than the Pliocene species, but juveniles of Recent *tasmanica* are very like fossil examples. The species also occurs in the Upper Beds at Muddy Creek (Pliocene) and it is possible that other specimens identified as *lamellosa* (or *roblini*) which is a synonym of *lamellosa* according to May (1919, p. 71), may prove to be *tasmanica*. The specimen previously identified as *Liotella capitata* Hedley is an eroded shell of the same species.

Material—The figured hypotype and 2 other specimens, Abattoirs Bore; 1 specimen, Hindmarsh Bore; 4 specimens, Muddy Creek (Upper Beds); 2 specimens, Recent, Tasmania; 2 specimens, Recent, Victoria (B.M. Coll.).

Stratigraphical Range—Kalimnan-Recent.

Geographical Distribution—New South Wales to Spencer Gulf, S. Aust.

Subfamily Collonilnae.

Genus Collonia Gray, 1850.

Collonia Gray, 1850, in M.E. Gray, Fig. Moll. Anim., 4, p. 87.

Type species (s.d. Fischer, 1885) *Delphinula marginata* Lamarck.

Collonia omissa sp. nov.

pl. 2, fig. 7.

Diagnosis—Apex flattened, whorls depressed below the suture, elsewhere convex. Umbilicus moderately wide, thickened and crenulate at the border. Aperture circular, moderately solid and thickened towards the umbilicus.

Description of Holotype—Shell small, flattened-globose, smooth, solid, of three turbinate whorls. Apex depressed, small, smooth and shining. Adult whorls somewhat flattened posteriorly below the suture, convex elsewhere. Sculpture of faint axial growth striae only. Umbilicus moderately wide, bordered with a crenulate callus. Aperture circular, moderately solid and thickened particularly at the umbilicus.

Dimensions—Height 1; maximum diameter 2 mm.

Type Locality—Abattoirs Bore, Adelaide; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, F15147.

Observations—The present species is probably the Pliocene descendant of *Collonia parvula* Tenison-Woods, which occurs almost ubiquitously in the Miocene of Victoria. *C. omissa* is similar in size and general aspect but differs in being more flattened than *parvula* and lacking the spiral striations. The umbilicus is crenulate, while in *parvula* it is simple. The aperture is thickened over the penultimate whorl in *omissa*.

Material—Holotype and 2 paratypes, Abattoirs Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Abattoirs Bore, Adelaide.

Subfamily TURBININAE.

Genus ASTRAEA Röding, 1798.

Astraea Röding ex Bolten, 1798. Mus. Bolt., p. 79.
(*Imperator* Montfort, 1810. Conch. Syst., 2, p. 198.)
(*Canthorbis* Swainson, 1840. Treat. Malac., pp. 216, 349.)

Type species (s.d. Suter, 1913) *Trochus imperialis* Gmelin = *heliotropium* Martyn.

Subgenus BELLASTRAEA Iredale, 1924.

Bellastraea Iredale, 1924. Proc. Linn. Soc. N.S.W., 49, (3), 197, p. 232.

Type species (o.d.) *Bellastraea kesteveni* Iredale.

Astraea (Bellastraea) hesperus sp. nov.

pl. 2, fig. 8.

Astraea (*Bellastraea*) *aster* (T. Woods). Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 100.

Diagnosis—Depressed, spire sunken, shoulder of whorl thin and sharp, produced at intervals into acute-angled spines about 8 per whorl on the penultimate whorl, each spine sculptured with threads radiating fan-wise; spines more widely spaced towards the aperture and inclined to be imbricating. Sculpture prominent, of rows of granules on the posterior part of the whorl increasing by intercalation to 5 rows near the aperture on the body whorl, and rows of imbricating fine scales on the anterior part of the whorl; increasing in number by intercalation. Base convex, sculptured with gemmulate spirals, which are finer towards the periphery and more strongly and distinctly gemmulate near the umbilicus, and waving axial growth threads. Umbilicus wide, margin thickened with parietal callus increasing in size with age.

Description of Holotype—Shell of moderate size, depressed-turbinate. Protoconch very small, sunken, of 2 smooth, flat turns, adult whorls three only slightly convex, sculptured with gemmulate spirals increasing by intercalation; posterior gemmules widely spaced in rows in anterior part of whorl, the spirals are rather surmounted by imbricating narrow scales marking the growth axials. Shoulder of whorl thin and sharply lamellar produced at intervals into acute-

angled spines, many of which are broken on the body whorl of the holotype. Each spine is ornamented with threads radiating fan-wise. Base of about equal convexity with the spire, sculptured from the shoulder to the umbilicus with six finely gemmulose spirals followed by one strongly gemmulose band and two obsolete rows of gemmules. Umbilicus wide, simple except for parietal callus which is crossed by numerous waving axials of growth. Aperture subcircular, inner lip rounded and reflected, outer lip angled and channelled at the periphery, excavate below, overhanging above.

Dimensions—Height 4; maximum diameter 11; minimum diameter 9 mm.

Type Locality—Abattoirs Bore; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, F15148.

Observations—Although there is a certain amount of resemblance between the early whorls of this species and *A.* (*B.*) *aster* Tenison-Woods, the adults differ conspicuously. *A.* (*B.*) *hesperus* is strongly sculptured, as compared with the almost smooth *A.* (*B.*) *aster*. There is also resemblance between *hesperus* and an unnamed species from Zanzibar in the B.M. Collection.

Material—Holotype, 6 paratypes, Abattoirs Bore; 1 paratype, Hindmarsh Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Abattoirs and Hindmarsh Bores, S. Aust.

Family PHASIANELLIDAE

Genus PHASIANELLA Lamarck, 1804.

Phasianella Lamarck, 1804. Ann. Mus. Hist. Nat. Paris, 4, (22), p. 295.
Phasianella Lamarck, Wenz, 1938. Handb. d. Palaozool. Gastr., p. 363 (synonymy).

Type species (s.d. Harris, 1897) *Phasianella turbinoides* Lamarck.

Phasianella dennanti Crespin

Phasianella dennanti Crespin, 1926. Proc. Roy. Soc. Vic. 38 (n.s.), p. 119, pl. 9, figs. 16, 17.
Phasianella dennanti Crespin. Ludbrook, 1941, Trans. Roy. Soc. S. Aust., 65, (1), p. 100.

Diagnosis—Five subventricose whorls in adult. Aperture elongate-ovate, rounded anteriorly, pointed posteriorly, inner lip everted. Colour markings where visible in square tessellated pattern. Suture impressed.

Dimensions—Height 14; diameter 8·25; height of aperture 5·75; height of aperture (inside measurement) 4·75 mm.

Type Locality—Muddy Creek, Upper Bed; Kalimnan.

Location of Holotype—Dennant Coll., Nat. Mus., Melbourne.

Observations—Although no colour markings are visible, one shell, differing in size, shape of whorls, and shape of aperture from the small species described below as *Pellax jejuna* sp. nov., appears to belong to *P. dennanti*. It is smaller in size than typical *dennanti*, having a height of 8 mm.

Material—1 specimen, Weymouth's Bore.

Stratigraphical Range—Pliocene; ?Balcombian.

Geographical Distribution—Keilor near Melbourne; Muddy Creek, Victoria; Adelaide, S. Aust.

Genus PELLAX Finlay, 1927.

Pellax Finlay, 1927. Trans. N.Z. Inst., 57, p. 368.

Type species (o.d.) *Phasianella huttoni* Pilsbry.

Pellax jejuna sp. nov.

pl. 2, fig. 9.

Diagnosis—Shell turbinate-conical, about twice as high as broad, whorls rapidly increasing in size and convexity, ornamented with oblique axial linear flame-coloured markings. Body whorl about two-thirds height of shell. Aperture expanded anteriorly, inner lip straight and reflected over umbilicus, somewhat effuse at base. Umbilicus closed.

Description of Holotype—Shell very small, turbinate-conical, thin, about twice as high as broad. Protoconch minute, sunken; whorls 4, subventricose, rapidly increasing in size and convexity, smooth, ornamented with oblique, axial, narrow linear, flame-coloured markings. Body whorl large, about two-thirds height of shell, spire small, moderately elevated. Suture linear, impressed. Aperture subovate, expanded somewhat anteriorly, angulate posteriorly. Inner lip simple, almost straight and reflected over the umbilicus, somewhat effuse at the base. Umbilicus closed.

Dimensions—Height 3; diameter 1·5; height of aperture 1 mm.

Type Locality—Weymouth's Bore, 310-330 feet; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, F15149.

Observations—Both Thiele (1935, p. 71) and Wenz (1938, p. 362) have placed *Pellax* in synonymy with *Eulithidium* Pilsbry (1898). The two are, however, dissimilar. *Eulithidium variegatum* (Carpenter), the type species of *Eulithidium*, is a minute, paucispiral, solid shell with a small depressed spire, quite unlike that of *Phasianella* or *Pellax*. It is also faintly axially ribbed under magnification and is perforate. *Eulithidium punctatum* (Carpenter) also has a small, depressed spire, and the body whorl is very large in comparison. There are fewer whorls in both species than in species of *Pellax*.

The present species, *jejuna*, is closely related to the Recent Australian species *rosea* and *virgo*, associated by Finlay with the New Zealand type species of the genus, *Pellax huttoni* (Pilsbry). The colour pattern is remarkably well preserved in the Weymouth's Bore specimens.

Material—Holotype, numerous paratypes, Weymouth's Bore; 5 paratypes, Hindmarsh Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Weymouth's and Hindmarsh Bores, Adelaide, S. Aust.

Family PHENACOLEPADIDAE.

Genus Phenacolepas Pilsbry, 1891.

Scutella Broderip, 1834. Proc. Zool. Soc., p. 47 (in part) (not *Scutella* Lamarck, 1816).
Scutellina Gray, 1947. Proc. Zool. Soc., 15, p. 168 (*non* Agassiz, 1841).
Phenacolepas Pilsbry, 1891. Nautilus, 5, p. 89 (nom. nov. for *Scutellina* Gray).
Phenacolepas Pilsbry. Wenz, 1938. Handb. Palaeozool. Gast., p. 432 (synonymy)

Type species (o.d.) *Scutella crenulata* Broderip.

Phenacolepas tela Ludbrook

Phenacolepas tela Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 88, pl. 4, fig. 19.

Diagnosis—Apex one-eighth distance from posterior border. Apex smooth, sculpture elsewhere of 80-90 radial ribs and about 11 raised sharp concentric ridges with very fine crowded concentric lirae on the interspaces. Ridges crowded posteriorly, widely spaced anteriorly.

Dimensions—Length 7·5; breadth 5·8; height 2·5 mm.

Type Locality—Abattoirs Bore, Adelaide; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T1648.

Observations—No further examples of this unique species have been found since it was described from Abattoirs Bore material.

Material—Holotype, T1648.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Abattoirs Bore, Adelaide.

Superfamily COCCULINACEA.

Family LEPETELLIDAE.

Genus Cocculinella Thiele, 1909.

Cocculinella Thiele, 1909, in Martini & Chemnitz, Syst. Conch. Cat., 2, (33), 539, p. 21.

Type species (monotypy) *Acmaea minutissima* E. A. Smith.

Cocculinella salisburyensis sp. nov.

pl. 2, fig. 1.

Cocculina praecompressa Chapman & Gabriel. Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 100.

Diagnosis—Shell very small, strongly laterally compressed, three times as long as wide, fairly low, apex at one-fifth from posterior.

Description of Holotype—Shell very small, strongly laterally compressed, narrowly rectangularly ovate, sides nearly parallel. Smooth except for concentric growth-lirae. Three times as long as wide, fairly low, apex at about one-fifth distance from posterior margin, slightly incurved.

Dimensions—Length 4·5; width 1·5; height 0·6; distance of apex from posterior margin 0·9 mm.

Type Locality—Tennant's Bore, Salisbury, S. Aust.; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, F15150.

Observations—This species is related to *C. praecompressa*, but it is narrower; the apex is nearer the posterior margin and the shell is less elevated. The genus is Indo-Pacific and Australasian, ranging in Australia from Miocene to Dry Creek Sands.

Material—Holotype and one paratype, Tennant's Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Tennant's and Abattoirs Bores, Adelaide District.

Superfamily LITTORINACEA.

Family LITTORINIDAE

Genus Tectarius Valenciennes, 1833.

Tectarius Valenciennes, 1833, in Humboldt, Obs. Zool., 2, p. 271.

Type species (monotypy) *Tectarius coronatus* Valenciennes = *Trochus pagodus* Linné.

Subgenus Nina Gray, 1850.

Nina J. E. Gray in M. E. Gray, 1850, Fig. Moll. Anim., 4, p. 78.

Type species (o.d.) *Trochus cumingi* Philippi.

Tectarius (Nina) adelaidensis (Cotton)

cf. *Astraea* sp. Ludbrook, 1941. Trans. Roy. Soc. S. Aust., 65, (1), p. 100.
Nina adelaidensis Cotton, 1947. Rec. S. Aust. Mus., 8, (4), p. 666, pl. 21, figs. 17, 18.

Diagnosis—Spire high, umbilicus wide, whorls sharply angulate with produced, sharp, hollow spines. A prominent nodulose spiral rib below the spinose angle.

Dimensions—Height 16; diameter 12, diameter including the last spine on the body whorl 15 mm.

Type Locality—Salisbury Bore, 350 feet.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T1730.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Salisbury Bore, 350 feet; Abattoirs Bore.

Superfamily RISSOACEA.

Family RISSOIDAE.

Subfamily Rissoinae

Genus Amphithalamus Carpenter, 1864.

Amphithalamus Carpenter, 1864. Rep. Brit. Ass. (Newcastle), 1863, pp. 537, 614, 656

Type species (monotypy) *Amphithalamus inclusus* Carpenter.

Subgenus Pisinna Monterosato, 1878.

Pisinna Monterosato, 1878, Giorn. Sci. Nat. Econ. Palermo 13, p. 86.
(*Estea* Iredale, 1915. Trans. N.Z. Inst., 47, p. 451.)

Type species (s.d. Fischer, 1885) *Rissoa punctulum* Philippi.

Amphithalamus (Pisinna) subbicolor sp. nov.

pl. 2, fig. 10.

Estea cf. *bicolor* (Petterd, 1881), Ludbrook, 1941, Trans. Roy. Soc. S. Aust., 65 (1), p. 100.

Diagnosis—Adult whorls flattened and evenly sloping; suture narrowly canaliculate. Body whorl generally conspicuously angled at the shoulder.

Description of Holotype—Shell minute, conical, solid, about twice as high as broad, smooth except for microscopic axial growth-lines, spire elevated. Protoconch smooth and somewhat flattened, of 1½ turns. Adult whorls 4, flattened and evenly sloping except for first whorl, which is slightly convex. Suture narrow and canaliculate. Body whorl about half total height of shell, conspicuously angled at the shoulder; angle between face of whorl and base about 120 deg. Aperture roundly ovate, slightly angled above, entire; outer lip simple, inner lip reflected over columella; columella rather straight.

Dimensions—Height 2; diameter 1; height of body whorl 1 mm.

Type Locality—Abattoirs Bore; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, F15151.

Observations—This species is broader than *bicolor*, into which it has previously been placed, and is more or less angulate at the periphery. It bears the closest resemblance in shape to "*Rissoa*" *ephamilla* Smith, from St. Helena.

Wenz (1939, p. 613) has syonymized *Estea* with *Pisinna* Monterosato, and in his original description of *Estea* Iredale (l.c., p. 451) states that *Pisinna* appears to be *Estea* + *Scrobs*. In view of the absence of recognizable differences between *Estea* and *Pisinna*, there appears to be nothing to support the separation of the two. There are, however, differences between *Pisinna* and *Scrobs* warranting their separation.

Material—Holotype and 10 paratypes, Abattoirs Bore; 23 paratypes, Hindmarsh Bore; 6 paratypes, Weymouth's Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Adelaide District.

Amphithalamus (Pisinna) chrysalidus (Chapman & Gabriel)

pl. 2, fig. 12.

Rissoa (*Onoba*) *chrysalida* Chapman & Gabriel, 1914, Proc. Roy. Soc. Vic., 26 (n.s.) (2), p. 322, pl. 28, figs. 32, 33.

Epigrus chrysalidus Chapman & Gabriel. Chapman & Crespin, 1928, Rec. Geol. Surv. Vic., 5 (1), p. 111.

Epigrus chrysalidus (Chapman & Gabriel), Ludbrook, 1941, Trans. Roy. Soc. S. Aust. 65 (1), p. 100.

Diagnosis—Pupiform, fairly large for the genus, apex very blunt, adult whorls 4, suture linear impressed, aperture small, about one-fifth height of shell.

Dimensions—Length 3·1; diameter 1·5 mm.

Type Locality—Mallee Bore No. 9, 254-256 feet; Kalimnan.

Location of Holotype—Geol. Surv. Vic. Coll.

Observations—No further specimens have been recovered since those from Abattoirs Bore; the species is well represented in the Kalimnan of Western Victoria.

Material—Numerous specimens, Upper Beds, Murray Creek, Vic. B.M. Coll.

Stratigraphical Range—Kalimnan—Dry Creek Sands.

Geographical Distribution—Port Phillip Bay, Vic.—Adelaide, S. Aust

Genus Merelina Iredale, 1915.

Merelina Iredale, 1916, Trans. N.Z. Inst., 47, p. 449.

Type species (o.d.) *Rissoa cheilostoma* T. Woods.

Subgenus Linemera Finlay, 1924.

Linemera Finlay, 1924, Trans. N.Z. Inst., 55, p. 438.

Type species (o.d.) *Linemera interrupta* Finlay nom. nov. for *Rissoa gradata* Hutton non Philippi.

Merelina (Linemera) variseulpta sp. nov.

pl. 2, fig. 11.

Merelina cf. *suprasculpta* May. Ludbrook, 1941, Trans. Roy. Soc. S. Aust., 65 (1), p. 100.

Diagnosis—Spire whorls clathrate, with 3 strong spirals on last whorl crossed by axials of equal strength. Interstices smooth or with faint axials only, intersections nodulose. Base with 4 spirals, more closely spaced than on body whorls, faintly crossed by the axials. Outer lip marked within by short cords corresponding to external spiral sculpture.

Description of Holotype—Shell minute, about twice as high as broad, elongate-conical. Protoconch smooth, glossy and prominent, of 1½ turns, adult whorls 4, moderately convex, suture impressed. Adult whorls clathrate, with prominent spirals increasing to 3 on the body whorl, crossed by equal axials, interspaces smooth or faintly crossed by axial striae; intersections nodulose. Base with 4 close spirals weaker than on spire whorls and more closely spaced, faintly crossed by axials. Aperture subovate, angulate above and rounded below; outer lip variced, marked internally by short cords corresponding to the internal spirals.

Dimensions—Height 3; diameter 1·6 mm.

Type Locality—Abattoirs Bore, Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, F15152.

Observations—*M.* (*L.*) *varisculpta* differs from *suprasculpta* (May) with which it has previously been compared in the differing and finer sculpture on the base, and the smooth interspaces between the clathrate sculpture. On *suprasculpta* the interspaces are spirally lirate.

Material—Holotype, one paratype, Abattoirs Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Abattoirs Bore, Adelaide.

Genus Turboella Leach, 1847.

Turboella Leach (in Gray), 1847, Proc. Zool. Soc., p. 152.
(*Pusillina* Monterosato, 1884, Nomencl. Conch. Medit., p. 56.)
(*Haurakia* Iredale, 1915, Trans. N.Z. Inst., 47, p. 449.)
Turboella Leach. Wenz, 1939, Handb. Palaeozool. Gast., p. 619 (synonymy).

Type species (o.d.) *Turbo parva* Da Costa.

Turboella praenovarensis sp. nov.

pl. 2, fig. 14.

Haurakia cf. *novarensis* Frauenfeld, Ludbrook, 1941, Trans. Roy. Soc. S. Aust., 65 (1), p. 100.

Diagnosis—Sculpture of fine close axial ribs, equal to the interspaces, about 30 on the body whorl, and spiral lirae, dominated by the axials, crossing the interspaces only. Spiral lirae weak in the early whorls, increasing in strength to the body whorl. Base convex, strongly spirally lirate and crossed by axials weaker than on whorls.

Description of Holotype—Shell roundly conical, whorls moderately convex, body whorl a little more than half height of shell. Protoconch prominent, of 2 smooth convex and somewhat elevated turns, adult whorls 3; suture linear, impressed. Sculpture of fine, close axial ribs about 30 per whorl extending from suture to suture and equal to the interspaces. Interspaces crossed by fine spirals, weaker than the axials, but increasing in strength towards the body whorl. Base convex with 8 spiral lirae faintly crossed by weakening axials. Aperture subovate elongate above and rounded below, outer lip variced, columella arcuate, somewhat excavate.

Dimensions—Height 3·3; diameter 1·5 mm.

Type Locality—Abattoirs Bore; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, F15153.

Observations—Previously compared to *novarensis* (Frauenfeld) the present species is possibly ancestral to *novarensis*. It resembles the Recent species very

closely, but the sculpture is finer and more definite, while the shells in general are larger in size than such specimens of *novarensis* as are available in the B.M. Collection.

Material—Holotype, 18 paratypes, Abattoirs Bore; 2 paratypes, Hindmarsh Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Abattoirs and Hindmarsh Bores, Adelaide

Turboella climattae sp. nov.

pl. 2, fig. 15.

*Hauraki*a cf. *demessa* Tate & May. Ludbrook, 1941, Trans. Roy. Soc. S. Aust., **65** (1), p. 100.

Diagnosis—Sculpture of prominent and strong axial ribs which are angulate at the shoulder and give the appearance of angulation to the whorl; 9 ribs on the body whorl, 8 on the penultimate whorl. Ribs crossed by two spiral lirae on each whorl; intersections nodulose. There is an infrasutural line of nodules with no corresponding lira, secondary to the primary sculpture. Base with 4 spiral lirae and faint growth axials.

Description of Holotype—Shell minute, elongate-turreted about twice as high as broad. Protoconch smooth and prominent of 1½ globose turns, adult whorls 4, sculptured with prominent, strong axial ribs, which are angulate at the shoulder and give an appearance of angulation to the whorls; 9 ribs on the body whorl, 8 on the penultimate whorl. Ribs crossed by 2 spiral lirae on each whorl, intersections nodulose. There is an infrasutural line on nodules, with no corresponding lira, secondary to the primary sculpture. Suture not marked. Base flatly convex, with 4 spiral lirae and faint growth axials. Aperture subovate, angled above and somewhat produced below. Outer lip thin with a varix behind. Columella curved.

Dimensions—Height 2·5; diameter 1·2 mm.

Type Locality—Hindmarsh Bore, 450-487 feet; Dry Creek Sands.

Location of Holotype—Tate Mus. Col., Univ. of Adelaide, F15154

Observations—This is a very beautiful little shell, strongly and conspicuously sculptured. It is nearest to *T. demessa* (Tate & May) with which it was previously compared, but the sculpture is distinct from that species.

Material—Holotype, Hindmarsh Bore; 3 paratypes, Weymouth's Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Adelaide District.

Genus Kaurnella Ludbrook, 1941.

Kaurnella Ludbrook, 1941, Trans. Roy. Soc. S. Aust., **65** (1), p. 88.

Type species (monotypy) *Kaurnella denotata* Ludbrook.

Kaurnella denotata Ludbrook

Kaurnella denotata Ludbrook, 1941, Trans. Roy. Soc. S. Aust., **65** (1), p 88, pl. 5, fig. 1.

Diagnosis—Stout, subglobose-conical; spire small, body whorl large. Whorls sculptured with numerous fine spiral lirae which are generally more prominent on the shoulder. Outer lip varicate; in some specimens there are as many as seven conspicuous varices on each whorl, while in others, the varices are absent or obsolete, being suggested merely by a faint tuberculation of the prominent lirae.

Dimensions—Height 3·1; diameter 2·2 mm.

Type Locality—Abattoirs Bore.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, T1644.

Observations—There is a considerable amount of variation in the strength of the varices on this species. Some specimens are strongly varicate and appear to be costate, while others have no appearance of costation and the varices are obsolete. There appears to be no other species, nor genus, with which the species

can be compared. It has been placed in the Rissoidae in which family it may be distinguished by its low spire and large body whorl, in addition to the widely spaced varices when they are present.

Material—6 paratypes, Abattoirs Bore; 18 specimens, Weymouth's Bore; 1 broken specimen, Hindmarsh Bore.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Adelaide District.

Genus CINGULA Fleming, 1828.

Cingula Fleming, 1818, Encycl. Brit. Supp. to ed. 4-6, 3 (1), p. 311.

Type species (s.d. Gray, 1847) *Turbo cingullus* Montagu.

Subgenus PELECYDIUM P. Fischer, 1885.

Pelecydium P. Fischer, 1871, in Folin & Perier, Fonds de la Mer, 1, p. 316 *nom. nud.*
Pelecydium Fischer, 1885, Man. de Conch., p. 721.
(*Epigrus* Hedley, 1903, Mem. Aust. Mus., 4, p. 355.)

Type species (monotypy) *Pelecydium venustulum* Folin.

Cingula (Pelecydium) cylindracea (Tenison-Woods).

pl. 2, fig. 16.

Rissoina cylindracea Tenison-Woods, 1878, Proc. Linn. Soc. N.S.W., 2, p. 266.
Rissoa ischna Tate, 1899b, Trans. Roy. Soc. S. Aust., 23 (2), p. 233 nom. mut. for *Rissoa cylindracea* (Tenison-Woods) non Krynicki, 1837.
Rissoa (Amphithalamus) simsoni Tate & May, 1900, Trans. Roy. Soc. S. Aust., 24, p. 100, pl. 26, fig. 76.
Epigrus cylindraceus (Tenison-Woods), Ludbrook, 1941, Trans. Roy. Soc. S. Aust., 65 (1), p. 100.
Epigrus cylindraceus (Tenison-Woods), Cotton, 1944, Id., 68 (2), p. 308.
Epigrus cylindracus (lapsus calami for *cylindraceus*) Tenison-Woods, Laseron, 1950, Rec. Aust. Mus., 22 (3), p. 276.

Diagnosis—Pupiform, whorls 5½. Suture linear. Protoconch of 2 large globose turns, adult whorls slightly convex.

Dimensions—Height 5; diameter 1·5 mm.

Location of Holotype—Hobart Museum (?).

Material—Hypotype and 2 specimens, Abattoirs Bore; 4 specimens, Hindmarsh Bore; 1 specimen, Weymouth's Bore.

Stratigraphical Range—Dry Creek Sands—Recent.

Geographical Distribution—Fossil—Adelaide District; Recent—N.S.W., Victoria and Tasmania.

Genus RISSOINA d'Orbigny, 1840.

Rissoina d'Orbigny, 1840, Voy. Amer. Merid. Moll., 5 (3), p. 395.

Type species (monotypy) *Rissoina inca* d'Orbigny.

Rissoina nivea Adams

Rissoina nivea Adams, 1851b, Proc. Zool. Soc., p. 265.
Rissoina lirata Angas, 1880, Proc. Zool. Soc., p. 417, pl. 40, fig. 11.
Rissoina lirata Angas, Dennant & Kitson, 1903, Rec. Geol. Surv. Vic. 1 (2), p. 144.
Rissoina nivea Adams, Ludbrook, 1941, Trans. Roy. Soc. S. Aust., 65 (1), p. 100.

Diagnosis—Finely ribbed with about 12 oblique ribs per whorl, obsolete anteriorly, strong on the body and penultimate whorls.

Dimensions—Height 4; diameter 1·3 mm.

Type Locality—Port Lincoln, S. Australia; Recent.

Location of Holotype—B.M. Coll. (Mus. Cuming).

Material—Holotype and one eroded example, Weymouth's Bore.

Stratigraphical Range—Dry Creek Sands—Recent.

Geographical Distribution—Southern Australia.

Rissoina elegantula Angas.

pl. 2, fig. 18.

Rissoina elegantula Angas, 1880, Proc. Zool. Soc., p. 417, pl. 40, fig. 10.
Rissoina elegantula Angas; Tate, 1890a, Trans. Roy. Soc. S. Aust., 13 (2), p. 177.
Rissoina elegantula Angas, Dennant & Kitson, 1903, Rec. Geol. Surv. Vic., 1 (2), p. 144.
Rissoina elegantula Angas, Ludbrook, 1941, Trans. Roy. Soc. S. Aust., 65 (1), p. 100.

Diagnosis—Longitudinally closely and regularly ribbed, about 8 per mm. on the body whorl and 6 per mm. on the penultimate whorl. Interstices, especially on the last whorl, crossed by fine lirae.

Dimensions—Height 5; diameter 2 mm.

Type Locality—Aldinga Bay, S. Australia; Recent.

Location of Holotype—B.M. Coll., No. 81. 4.29.2.

Material—Holotype and 4 specimens, Hindmarsh Bore; 1 specimen, Weymouth's Bore.

Stratigraphical Range—Dry Creek Sands—Recent.

Geographical Distribution—Queensland to S. Australia.

Rissoina aff. **elegantula** Angas.

A single specimen, imperfect, from Hindmarsh Bore, has sculpture similar in character to that of *R. elegantula*. The axial ribs are, however, less fine and frequent than in that species, and the axial ribs spiral lirae are much more clearly defined. In the absence of further material, accurate diagnosis is deferred.

Rissoina tinela sp. nov.

pl. 2, fig. 19.

Diagnosis—Whorls convex; body whorl large. Suture impressed; sculpture of numerous close, fine, spiral threads.

Description of Holotype—Shell elongate, turreted, fairly thin. Whorls convex, body whorl large, two-thirds total height of shell. Protoconch small, of 1½ smooth turns, adult whorls 5, rapidly increasing. Suture strongly impressed. Sculpture of numerous fine spiral threads, wider than interspaces; interspaces under magnification with fine microscopic radials. Aperture large, angulate behind and produced in front. Outer lip effuse, variate. Columella gently arcuate, inner lip reflected slightly.

Dimensions—Height 5; diameter 2·5; height of body whorl 3 mm.

Type Locality—Hindmarsh Bore, 450-487 feet; Dry Creek Sands.

Location of Holotype—Tate Mus. Coll., Univ. of Adelaide, F15155.

Observations—This unique specimen is somewhat like *R. lintea* Hedley & May and *R. elegantula* Angas. It differs in sharpe from *R. lintea* in that the whorls are convex and the suture impressed, not canaliculate as in *lintea*. The sculpture is reminiscent of *R. elegantula*, but is very much finer and only obvious under magnification.

Material—Holotype, Hindmarsh Bore, 450-487 feet; Dry Creek Sands.

Stratigraphical Range—Dry Creek Sands.

Geographical Distribution—Hindmarsh Bore.

Family TORNIDAE.

Subfamily Omphalotropinae.

Genus Pseudoliotia Tate, 1898.

Pseudoliotia Tate, 1898a, Trans. Roy. Soc. S. Aust., 22 (1), p. 71.

Type species (monotypy) *Cyclostrema micans* A. Adams.

Pseudoliotia angasi (Crosse)

pl. 2, fig. 20.

Cyclostrema micans Adams, 1850, Proc. Zool. Soc., 18, p. 44 (in part).
Liotia angasi Crosse, 1864, Journ. de Conch., 12, p. 343, pl. 13, fig. 4.

Liotia angasi Crosse, Tryon, 1888, Man. Conch., 10, p. 68, pl. 31, figs. 17, 18.
Liotia angasi Crosse, Tate, 1890, Trans. Roy. Soc. S. Aust., 13 (2), p. 177.
Cyclostrema micans Adams, Tate, 1897, Trans. Roy. Soc. S. Aust., 21, p. 43.
Cyclostrema micans A. Adams, Dennant & Kitson, 1903, Rec. Geol. Surv. Vic., 1 (2), p. 145.
Pseudoliotia angasi Crosse, Cotton & Godfrey, 1938, Mal. Soc. S. Aust., 1, p. 8.

Diagnosis—A small *Pseudoliotia*, solid, shining, rather coarsely sculptured, spire smooth at the apex; early whorls rounded, postembryonic whorls angulate, developing first one spiral cord increasing to one fine subsutural cord and three prominent medial cords on the body whorl with an additional thick cord bounding the umbilicus. Cords crossed and strongly tuberculated by axial spirals which increase in strength and distance apart and number about 20 on the body whorl.

Dimensions—Height 1·5; diameter 3 mm.

Type Locality—St. Vincent Gulf, S. Australia.

Location of Holotype—B.M. Coll., No. 70. 10.26.139.

Observations—The two species, *P. micans* Adams and *P. angasi* Crosse, have been confused in South Australian literature and the name *micans* has been omitted from the Recent list by Cotton & Godfrey (1938, p. 8) in the erroneous belief that the type locality of *micans* is Japan. This error was introduced by Tate (1899, p. 223) and has apparently not been rectified since. The type locality, Port Lincoln (Adams, 1850, p. 44), is confirmed by the tablet of type specimens in the British Museum. The species should, therefore be replaced on the South Australian list. *P. angasi* Crosse, alleged to be conspecific with *micans*, is a very similar shell, but more coarsely sculptured than *micans*. One of the 13 specimens on the tablet of types of *P. micans* is *P. angasi*. It is impossible to tell without examination of the actual specimens whether Tate's subspecies *simplicior* (1898, p. 71) is *micans* or *angasi*, but the name indicates that it is *micans*. Tate later (1899, p. 223) erroneously listed in synonymy this subspecies as *gracilior*. Dry Creek Sands specimens are not *micans*, but the more boldly sculptured *angasi*.

Material—The figured hypotype and 2 other specimens, Tennant's Bore, 1 broken specimen, Abattoirs Bore, holotype and 1 paratype, B.M. Coll., No 70. 10.26.139.

Stratigraphical Range—Dry Creek Sands-Recent.

Geographical Distribution—South Australia.

LIST OF REFERENCES

ADAMS, A., 1850. An Arrangement of Stomatellidae, including the Characters of a New Genus and of several new species. Proc. Zool. Soc., 18, pp. 29-40.

ADAMS, A., 1851a. A Catalogue of the Species of Emarginula, a Genus of Gasteropodous Mollusca, belong to the Family Fissurellidae, in the Collection of H. Cuming, Esq. Proc. Zool. Soc., 19, pp. 82-92.

ADAMS, A., 1851b. Description of sixteen new species of Rissoina, a genus of Marine Gasteropodous Mollusks from the Cumingian Collection. Proc. Zool. Soc., 19, pp. 264-267.

ADAMS, A., 1860. On Some new Genera and Species of Mollusca from Japan. Annals & Mag. Nat. Hist., ser. 3, 6, pp. 331-337.

ADAMS, A., 1863. On the Genera and Species of Liotiinae found in Japan. Proc. Zool. Soc., pp. 71-76.

ADAMS, A., 1865. On Some New Genera of Mollusca from the Seas of Japan. Annals & Mag. Nat. Hist., ser. 3, 15, pp. 322-324.

ADAMS, H., and ADAMS, A., 1853-1858. The Genera of Recent Mollusca. 3 vols. London. John van Voorst.

ANGAS, G. F., 1880. Further additions to the Marine Molluscan Fauna of South Australia, with Descriptions of New Species. Proc. Zool. Soc., pp. 415-417, pl. 40.

ASHBY, E., 1940. A New Fossil Cryptoplax from the Pliocene of South Australia. Trans. Roy. Soc. S. Aust., 64 (2), p. 266. Text fig.

ASHBY, E., and COTTON, B. C., 1936. South Australian Fossil Chitons. Rec. S. Aust. Mus., 5 (4), pp. 509-512, text figs. 1-2.

ASHBY, E., and COTTON, B. C., 1939. New Fossil Chitons from the Miocene and Pliocene of Victoria. Rec. S. Aust. Mus., 6 (3), pp. 209-242, pls. 19-21.

BLAINVILLE, H. M. D., DE, 1818. In Dictionnaire des Sciences Naturelles, 12.
BRODERIP, W. J., 1834. Description of a new Genus of Gasteropoda. Proc. Zool. Soc., pp. 47-49.
CARPENTER, P. P., 1864. Supplementary Report on the Present State of our Knowledge with regard to the Mollusca of the West Coast of America. Rep. Brit. Ass. Adv. Sci. (Newcastle, 1863), pp. 517-686.
CHAPMAN, F., CRESPIN, I., and KEBLE, R. A., 1928. The Sorrento Bore, Mornington Peninsula. Rec. Geol. Surv. Vic., 5 (1), 195 pp., 12 pls.
CHAPMAN, F., and GABRIEL, C. J., 1914. Description of New and Rare Fossils obtained by Deep Boring in the Mallee. Part 2. Mollusca. Proc. Roy. Soc. Vic., 26 (2), n.s., pp. 301-330, pls. 24-28.
CHAPMAN, F., and GABRIEL, C. J., 1923. A Revision and Description of the Australian Tertiary Patellidae, Patelloididae, Cocculinidae and Fissurellidae. Proc. Roy. Soc. Vic., 36 (n.s.) (1), pp. 22-40, pls. 1-3.
COTTON, B. C., 1944. Recent Australian Species of the Family Rissoidae (Mollusca). Trans. Roy. Soc. S. Aust., 68 (2), pp. 286-314, pl. 16.
COTTON, B. C., 1947. Some Tertiary Fossil Molluscs from the Adelaidean Stage (Pliocene) of South Australia. Rec. S. Aust. Mus., 8 (4), pp. 653-670.
COTTON, B. C., 1952. The Mollusca of the Adelaidean Stage. Appendix 4 to Miles, K. R. Geology and Underground Water Resources of the Adelaide Plains Area. Geol. Surv. S. Aust. Bull. 27, pp. 239-249.
COTTON, B. C., and GODFREY, F. K., 1933. South Australian Shells. Part 9. S. Aust. Nat., 15 (1), pp. 14-24, pl. 1.
COTTON, B. C., and GODFREY, F. K., 1938. A Systematic List of the Gastropoda . . . Mal. Soc. S. Aust., 1.
COTTON, B. C., and GODFREY, F. K., 1940. The Molluscs of South Australia. Part 2. Scaphopoda, Cephalopoda, Aplacophora, and Crepipoda. Handbook British Science Guild. Adelaide.
COTTON, B. C., and LUDBROOK, N. H., 1938. Recent and Fossil Species of the Scaphopod Genus Dentalium in Southern Australia. Trans. Roy. Soc. S. Aust., 62 (2), pp. 217-228, pl. 12.
COTTON, B. C., and WEEDING, B. J., 1941. The Correlation of Recent and Fossil Crepipoda (Mollusca) of the Australian Sub-Region. Rec. S. Aust. Mus., 6 (4), pp. 435-450.
CRESPIN, I., 1926. The Geology of Green Gully, Keilor, with special reference to the Fossiliferous Beds. Proc. Roy. Soc. Vic., 38 (n.s.), pp. 100-124, pls. 7-9.
CRESPIN, I., 1943. The Stratigraphy of the Tertiary Marine Rocks in Gippsland, Victoria. Commonwealth Dept. Supp. & Shipp., Min. Res. Surv. Bull. 9 (Pal. Ser. 4) (mimeographed)
CROSSE, H., 1864. Description d'éspèces nouvelles provenant de l'Australie méridionale. Journ. de Conch., 12, pp. 339-346, pl. 13.
DALL, W. H., 1882. On the General of Chitons. Proc. U.S. Nat. Mus., 4, pp. 279-291.
DENNANT, J., and KITSON, A. E., 1903. Catalogue of the Described Species of Fossils (except Bryozoa and Foraminifera) in the Cainozoic Fauna of Victoria, South Australia and Tasmania. Rec. Geol. Surv. Vic., 1 (2), pp. 89-147.
ETHERIDGE, R., JUN., 1878. A Catalogue of Australian Fossils. Camb. Univ. Press.
FINLAY, H. J., 1924. New Zealand Tertiary Rissoids. Trans. N.Z. Inst., 55, pp. 480-494, 1 pl.
FINLAY, H. J., 1927. A Further Commentary on New Zealand Molluscan Systematics. Trans. N.Z. Inst., 57, pp. 320-485.
FISCHER, P., 1871. In Folin, L. de & Perier, L., 1867-1871. Les Fonds de la Mer, I.
FISCHER, P., 1885. Manuel de Conchyliologie. Paris. 1369 pp. 23 pls.
FLEMING, J. ("Q.Q."), 1818. Conchology. Supplement to 4th, 5th and 6th Editions Encyclopaedia Britannica, 3, pp. 284-316.
GRAY, J. E., 1821. A Natural Arrangement of Mollusca, according to their internal structure. Lond. Med. Repos., 15, pp. 229-239.
GRAY, J. E., 1843. Notes on the Materials at present existing towards a Fauna of New Zealand. In Dieffenbach's Travels in New Zealand, 2, pp. 177-265.
GRAY, J. E., 1847. A List of the Genera of Recent Mollusca, their Synonyma and Types. Proc. Zool. Soc., 15, pp. 129-219.
GRAY, J. E., 1857. Guide to the Systematic Distribution of the Mollusca in the British Museum. Part I.
GRAY, M. E., 1850. Figures of Molluscous Animals, 4.
GUILDING, L., 1830. Observations on the Chitonidae. Zool. Journ., 5 (17a), pp. 25-35.
HANLEY, S., 1855. The Shells of Linnaeus.
HARRIS, G. F., 1897. Catalogue of Tertiary Mollusca in the Department of Geology, British Museum (Natural History). Part 1. The Australasian Tertiary Mollusca. London. Brit. Mus. (Nat. Hist.).
HEDLEY, C., 1902-3. Scientific Results Trawling Expedition H.M.C.S. Thetis off the Coast of New South Wales. Mollusca. Memoir 4, Parts 5 and 6, Aust. Mus., Sydney.

HERRMANNSEN, A. N., 1846. Indicis Generum Malacozoorum, 1.
HOWCHIN, W., 1936. Notes on the Geological Sections obtained by Several Borings situated on the Plains between Adelaide and Gulf St. Vincent. Part 2—Cowandilla (Government) Bore. Trans. Roy. Soc. S. Aust., 60, pp. 1-34.
IREDALE, T., 1915. Commentary on Suter's Manual. Trans. N.Z. Inst., 47, pp. 417-497.
IREDALE, T., 1924. Results from Roy Bell's Molluscan Collections. Proc. Linn. Soc. N.S.W., 49 (3), 197, pp. 179-278, pls. 33-36.
IREDALE, T., 1929. Queensland Molluscan Notes, No. 1. Mem. Qld. Mus., 9 (3), pp. 261-297, pls. 30-31.
IREDALE, T., 1930. Some Notable Name Changes. Aust. Zool., 6, p. 175.
IREDALE, T., 1930. Australian Molluscan Notes, No. 2. Rec. Aust. Mus., 19 (5), pp. 267-340.
JEFFREYS, J. G., 1867. Fourth Report on Dredging among the Shetland Isles. Ann. & Mag. Nat. Hist., ser. 3, 20, pp. 247-254.
LAMARCK, J. B., 1801. Système des Animaux sans Vertèbres.
LAMARCK, J. B., 1804. Suite des Mémoires sur les Fossiles des Environs de Paris. Genre 35-37. Ann. Mus. d'Hist. nat. Paris, 4 (22).
LAMARCK, J. B., 1819. Histoire naturelle des Animaux sans Vertèbres, 6.
LASERON, C. F., 1950. Review of the Rissoidae of New South Wales. Rec. Aust. Mus., 22 (3), pp. 257-287.
LINNÉ, C., 1758. Systema Naturae, ed. 10.
LUDBROOK, N. H., 1941. Gastropoda from the Abattoirs Bore, Adelaide, South Australia, together with a list of some miscellaneous fossils from the Bore. Trans. Roy. Soc. S. Aust., 65 (1), pp. 79-102, pls. 4, 5.
LUDBROOK, N. H., 1954. The Molluscan Fauna of the Pliocene Strata underlying the Adelaide Plains. Part 1. Trans. Roy. Soc. S. Aust., 77, pp. 42-64.
LUDBROOK, N. H., 1955. *ibid.* Part II. Trans. Roy. Soc. S. Aust., 78, pp. 18-87, pls. 1, 2.
McCOY, F., 1876. Prodromus of the Paleontology of Victoria. Decade 3, Geol. Surv. Vic. Spec. Pub.
MIDDENDORFF, A. T. VON, 1848. Beiträge zu einer Malacozoologia Rossica, 1. Mem. Acad. imp. Sci. St. Petersbourg, ser. 6, 8 (2) (sc. nat. 6), pp. 67-215, pls. 1-14.
MONTEROSATO, T. A. DI, 1878. Enumerazione e sinonimia delle Conchiglie Mediterranee. Giorn. Sci. Nat. Econ., 13, pp. 61-115.
MONTEROSATO, T. A. DI, 1884. Nomenclatura Generica e Specifica di alcune Conchiglie Mediterranee.
MONTFORT, D. DE, 1810. Conchyliologie Systématique, 2, 676 pp.
NEWTON, R. B., AND HARRIS, G. F., 1894. A Revision of the British Eocene Scaphopoda with Descriptions of some new Species. Proc. Malac. Soc., 1 (2), pp. 63-69. 1 text fig.
d'ORBIGNY, A., 1840. Voyage dans l'Amérique Méridionale. Mollusca, 5 (3).
PARTINGTON, C. F., 1835. British Cyclopedia of Natural History, 2.
PHILIPPI, R. A., 1844. Enumeratio Molluscorum Siciliae, 2.
PHILIPPI, R. A., 1847. Versuch einer systematischen Eintheilung des Geschlechtes Trochus. Zeits. Malakzool. Feb.
PILSBRY, H. A., 1889. Tryon's Manual of Conchology, 11.
PILSBRY, H. A., 1890. ibid., 12.
PILSBRY, H. A., 1891. On the Use of the Generic Name Scutellina. Nautilus, 5 (8), pp. 88-89.
PILSBRY, H. A., and SHARP, B., 1897-8. Scaphopoda. Tryon's Manual of Conchology, 17, pp. 1-280, pls. 1-39.
PRITCHARD, G. B., 1896. A Revision of the Fossil Fauna of the Table Cape Beds, Tasmania, with Descriptions of New Species. Proc. Roy. Soc. Vic., 8 (n.s.), pp. 74-150, pls. 2-4.
RISSO, A., 1826. Histoire Naturelle des principales Productions de l'Europe méridionale, 4.
RÖDING, P. F., 1798. Museum Boltenianum, Hamburg, 2.
SARS, M., 1859. Bidrag til en Skildring af den arctiske Molluskfauna ved Norges nordlige Kyst. Forhand. Videns. Selsk. Christiania. Aar 1858.
SOWERBY, G. B., 1894. Description of a New Species of Marine Shells from Hong Kong. Proc. Malac. Soc., 1, p. 158.
STOLICZKA, F., 1868. Cretaceous Fauna of Southern India. Mem. Geol. Surv. India, Pal. Indica 2.
SUTER, H., 1913. Manual of New Zealand Mollusca, 1,120 pp.
SWAINSON, W., 1840. A Treatise on Malacology. London.
SWAINSON, W., 1855. On the Characters of Astele, a new Division in the Family of Trochinae or Trochiform Shells; . . . . Proc. Roy. Soc. van Diemen's Land, Tasmania, 3 (1), pp. 36-41, pl. 6.
TATE, R., 1887. The Lamellibranchs of the older Tertiary of Australia. Part 2. Trans. Roy. Soc. S. Aust., 9, pp. 142-200, pls. 14-20.
TATE, R., 1890a. On the Discovery of Marine Deposits of Pliocene Age in Australia. Trans. Roy. Soc. S. Aust., 13 (2), pp. 172-180.

Tate, R., 1890b. The Gastropods of the Older Tertiary of Australia (Part 3). Trans. Roy. Soc. S. Aust., 13 (2), pp. 185-235, pls. 5-13.

Tate, R., 1898. On Two Deep-level Deposits of Newer Pleistocene Age in South Australia. Trans. Roy. Soc. S. Aust., 22 (1), pp. 65-71.

Tate, R., 1899. A Revision of Australian Cyclostrematidae and Liotiidae. Trans. Roy. Soc. S. Aust., 23 (2), pp. 213-248, pls. 6, 7.

Tate, R., 1899. A Revision of the Older Tertiary Mollusca of Australia. Part 1. Trans. Roy. Soc. S. Aust., 23 (2), pp. 249-277.

Tate, R., and Dennant, J., 1893. Correlation of the Marine Tertiaries of Australia. Part 1. Trans. Roy. Soc. S. Aust., 17 (1), pp. 203-226.

Tate, R., and Dennant, J., 1895. Correlation of the Marine Tertiaries of Australia. Part 2. Victoria. Trans. Roy. Soc. S. Aust., 19 (1), pp. 108-121.

Tate, R., and May, W. L., 1900. Descriptions of New Genera and Species of Australian Mollusca (chiefly Tasmanian). Trans. Roy. Soc. S. Aust., 24 (2), pp. 90-103.

Thiele, J., 1893. In Troschel, F. H. Das der Schnecken zur Begründung einer naturlichen Classification, 2.

Thiele, J., 1909. Cocculinoidea und die Gattungen Phenacolepas and Titiscania. In Martini and Chemnitz, Systematisches Conchylien-Cabinet., 2 (33), 539.

Tryon, W., 1888. Manual of Conchology, 10.

Valenciennes, A., 1833. Coquilles Fluviatiles Bivalves du Nouveau Continent, recoilles pendant le voyage de Mm. de Humboldt et Bompland. Humbolt & Bompland, Recueil d'Observ. de Zool. et d'Anat. Comp., (2), pp. 217-339.

Wenz, W., 1938. Gastropoda. Handb. Paläozool., 2, pp. 480-720.

Woods, J. E. Tenison-, 1876a. On Some Tertiary Fossils from Table Cape. Proc. Roy. Soc. Tas. for 1875, pp. 13-26.

Woods, J. E. Tenison-, 1876b. Description of New Tasmanian Shells. Proc. Roy. Soc. Tas. for 1875, pp. 134-162.

EXPLANATION OF PLATES

PLATE 1

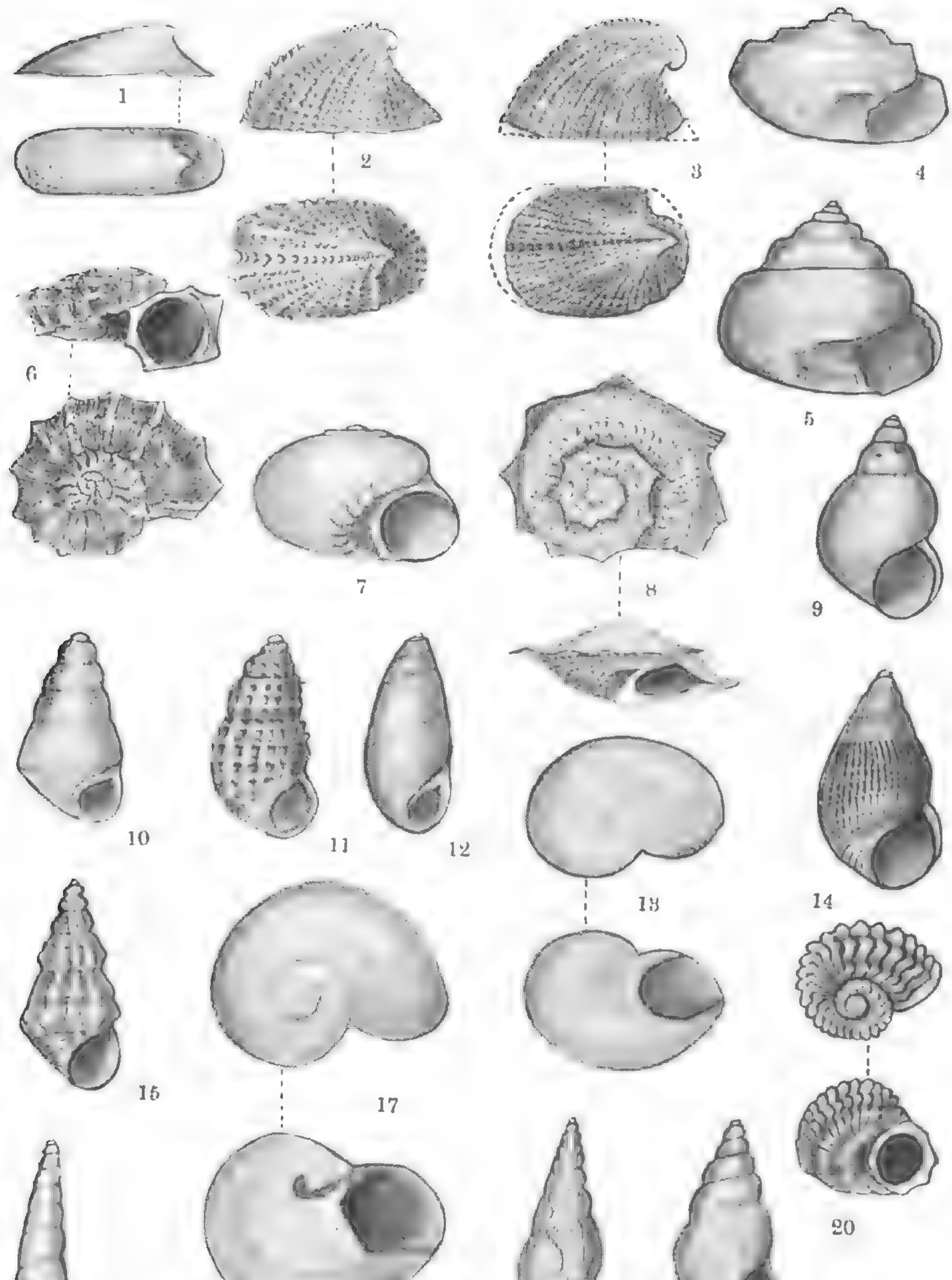
Fig. 1.—*Siphonodentalium (Pulsellum) adelaidense* sp. nov., holotype, x 5.
Fig. 2.—*Cadulus (Gadila) acuminatus* Tate, hypotype, Dry Creek Bore, x 5.
Fig. 3.—*Cadulus (Dischides) yatalensis* sp. nov., holotype, x 5.
Fig. 4.—*Cadulus (Dischides) yatalensis* sp. nov., paratype, Abattoirs Bore, x 5.
Fig. 5.—*Dentalium (Fissidentalium) mawsoni* sp. nov., holotype, x 1·85.
Fig. 6.—*Dentalium (Fissidentalium) mawsoni* sp. nov., paratype, R. Murray Cliffs, x 2.
Fig. 7.—*Dentalium (Antalis) denotatum* sp. nov., paratype, Abattoirs Bore, x 3; apex and aperture enlarged.
Fig. 8.—*Dentalium (Antalis) denotatum* sp. nov., paratype, Abattoirs Bore, apical portion x 10.
Fig. 9.—*Dentalium (Antalis) denotatum* sp. nov., holotype, x 3.
Fig. 10.—*Dentalium (Dentalium) latesulcatum* Tate, holotype, x 2. Fig. 10a. Detail of rib sculpture.
Fig. 11. *Dentalium (Dentalium) latesulcatum* Tate, holotype of *D. (Paradentalium) howchini* Cotton & Ludbrook, x 2.
Fig. 12.—*Dentalium (Dentalium) latesulcatum* Tate, 7-ribbed juvenile, Abattoirs Bore, x 4.
Fig. 13.—*Dentalium (Dentalium) latesulcatum* Tate, 13-ribbed juvenile, x 2.
Fig. 14.—*Dentalium (Dentalium) latesulcatum* Tate, 13-ribbed immature specimen, Weymouth's Bore, x 2.

PLATE 2

Fig. 1.—*Cocculinella salisburyensis* sp. nov., holotype, Tennant's Bore, x 5·8.
Fig. 2.—*Emarginula didactica* sp. nov., holotype, Abattoirs Bore, apical and lateral views, x 5·2.
Fig. 3.—*Emarginula dilatoria* sp. nov., holotype, Hindmarsh Bore, x 5·2.
Fig. 4.—*Spectamen planicarinatum* sp. nov., holotype, Abattoirs Bore, x 7.
Fig. 5.—*Spectamen praecursor* sp. nov., holotype, Weymouth's Bore, x 5·2.
Fig. 6.—*Liotina (Munditia) tasmanica* Tenison-Woods, hypotype, Abattoirs Bore, x 4·3.
Fig. 7.—*Collonia omissa* sp. nov., holotype, Abattoirs Bore, x 4·3.
Fig. 8.—*Astrea (Bellastrea) hesperus* sp. nov., holotype, Abattoirs Bore, apical and lateral views, x 2·6.
Fig. 9.—*Pellax jejuna* sp. nov., holotype, Weymouth's Bore, x 8·6.
Fig. 10.—*Amphithalamus (Pisinna) subbicolor* sp. nov., holotype, Abattoirs Bore, x 8·6.
Fig. 11.—*Merelina (Linemera) variisculpta* sp. nov., holotype, Abattoirs Bore, x 8·6.
Fig. 12.—*Amphithalamus (Pisinna) chrysalidus* (Chapman & Gabriel), hypotype, Muddy Creek, B.M. Coll., G 39560, x 5·2.
Fig. 13.—*Teinostoma depressulum* Chapman & Gabriel, hypotype, Hindmarsh Bore, x 13.
Fig. 14.—*Turboella praenovarensis* sp. nov., holotype, Abattoirs Bore, x 8·6.
Fig. 15.—*Turboella climatiae* sp. nov., holotype, Hindmarsh Bore, x 10·4.

Fig. 16.—*Cingula* (*Pelecydium*) *cylindracea* (Tenison-Woods), hypotype, Abattoirs Bore, x 5·2.
Fig. 17.—*Starkeyna pulcherrima* (Chapman & Gabriel), hypotype, Abattoirs Bore, x 6.
Fig. 18.—*Rissoina elegantula* Angas, hypotype, Hindmarsh Bore, x 7.
Fig. 19.—*Rissoina tinela* sp. nov., holotype, Hindmarsh Bore, x 6.
Fig. 20.—*Pseudoliotia angasi* (Crosse), holotype, Holden's Bore, x 6.


1
2
3
4
5
6
7
8
9
10
a
11
12
13
14


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
NHL

MICROFOSSILS FROM PLEISTOCENE TO RECENT DEPOSITS, LAKE EYRE, SOUTH AUSTRALIA.

BY N. H. LUDBROOK

Summary

Samples from sands, clays and limestones on the south-eastern corner of Lake Eyre were found to contain remains of fresh or brackish water microscopic plants and animals which inhabit inland and coastal lagoons, together with species of brackish water foraminifera. Deposition probably took place during Pleistocene high sea levels.

MICROFOSSILS FROM PLEISTOCENE TO RECENT DEPOSITS, LAKE EYRE, SOUTH AUSTRALIA.

By N. H. Ludbrook*

[Read 14 April 1955]

I. SUMMARY

Samples from sands, clays and limestones on the south-eastern corner of Lake Eyre were found to contain remains of fresh or brackish water microscopic plants and animals which inhabit inland and coastal lagoons, together with species of brackish water foraminifera. Deposition probably took place during Pleistocene high sea levels.

II. INTRODUCTION

Samples from two shallow boreholes sunk with a post-hole digger on the south-eastern corner of Lake Eyre and from a thick shell bed 36 feet above the present level of the lake were submitted for routine micropalaeontological examination by Mr. D. King, Geologist, South Australian Department of Mines, who was a member of the party led by Mr. Warren Bonython to Lake Eyre North, 400 miles north of Adelaide in May, 1953. The object of the expedition was to investigate further the geography and geology of the lake and the occurrence of native sulphur observed on the lake shore in December, 1951, after the flooding in 1949-50.

Bore No. 1 situated on the flat between dunes, Arbitrary Reduced Level of surface 110·75 ft., passed through the following strata:

0ft. 0in. to 0ft. 6in.: Yellow-brown, very fine, slightly clayey quartz sand with grit. Residue after washing consists of subangular quartz grains usually etched and pitted on the surface, some large grains of opaline silica and an occasional oolite of calcite.

0ft. 6in. to 2ft. 4in.: Fine yellow-brown quartz sand, similar to that at the surface.

2ft. 4in. to 4ft. 6in.: Yellow-brown fine clayey sand, washed residue of subangular quartz grains with a little oolitic calcite.

4ft. 6in. to 6ft. 6in.: Yellow-brown fine clayey sand, washed residue of subangular quartz grains of varying size with well-rounded grains of cryptocrystalline silica.

6ft. 6in. to 7ft. 9in.: Pale yellow-brown coarse to gritty sand with some gypsum; washed residue mainly of quartz grains of varying size and some gypsum fragments.

7ft. 9in. to 10ft. 3in.: Brown clay with fine and crystalline gypsum and quartz grit; washed residue of quartz grains of varying size with both seed and crystalline gypsum.

10ft. 3in. to 12ft. 10in.: Fine gypseous sand and clay; washed residue of large subrounded quartz grains much etched on the surface.

12ft. 10in. to 16ft. 4in.: Light brown sandy clay; washed residue of coarse quartz grains, many of them rather flat and of even size, and some gypsum crystals.

16ft. 4in. to 18ft. 8in.: Banded vari-coloured plastic clay; washed residue similar to the previous.

* Department of Mines, Adelaide. Published with the permission of the Director of Mines.

18ft. 8in. to 21ft. 4in.: Fine gravel with white limestone fragments; the coarse fraction of the washed residue consists of large quartz grains finely etched on the surface, and fragments of porcellanite and limestone.

21ft. 4in. to 22ft. 0in.: Black clay; the finer fraction (passing through 20 mesh) of the washed residue consists of subangular quartz grains with some limestone fragments. Also present are a number of platy grains of saponite with laminar intergrowths of finely divided pyrite.

22ft. 0in. to 22ft. 5 in.: Hard white dolomitic limestone with a gastropod mould. Such friable material as could be washed free of clay yielded white limestone fragments, subangular quartz grains some of them flat, and plates of pyrite crystals.

Bore No. 4.—Situated half mile south-east of Prescott Point at the north of Sulphur Peninsula, passed through:

0ft. to 2ft. 3in.: Pale brown clayey sand; washed residue of medium fairly even-sized subangular quartz grains with some limestone fragments.

2ft. 3in. to 3ft. 6in.: Grey sandy clay; washed residue of fine angular and subangular quartz grains, some so little worn as to still retain their crystalline form.

3ft. 6in. to 12ft. 0in.: Brown clay; washed residue of angular quartz grains, some very fresh, and an occasional grain of pyrite.

12ft. 0in. to 16ft. 10in.: Blue, very sticky clay; washed residue of medium-sized subangular quartz grains and calcite fragments, with authigenic pyrite some of which is intergrown with saponite.

16ft. 10in. to 17ft. 0in.: Hard white limestone, the friable portion of which was washed, leaving a residue of medium-sized subangular quartz grains, white calcite fragments and a pale green mineral of the beidellite-nontronite series, held together by calcite.

Without exception, the samples were fossiliferous, almost all having oogonia of *Chara* and relatively fewer heavily calcified valves of ostracoda and tests of "*Rotalia*" *beccarii*. The distribution of the organisms is shown in tabulated form at the end of the paper. The sands and sandy clays in Borehole 1 from the surface to 16ft. 4in. apparently represent the most favourable environment for their development; it is suggested that these represent a period of increasing salinity in the lake.

Two other samples were examined for identifiable microfossils with negative results:

1. Grey clay interstratified with limestone from Position B, point at small island with sand spit.

   Very little residue remained after washing, and this consisted mainly of flat, worn grains of calcite with some angular quartz grains.

2. Dense white clayey limestone taken from 3ft. 6in. to 4ft. 6in. in a bore at Locality C.

The only organic remains are horny tubes of unidentified origin. The most interesting sample was taken at position M from the upper shell bed, consisting almost entirely of shells of *Coxiella gilesi* (Angas). The unconsolidated matrix was found to contain numerous valves of two species of ostracoda and thin-shelled, well-preserved tests of a form of "*Rotalia*" *beccarii*, together with a small number of oogonia of *Chara*. One broken fragment of the pelecypod *Corbiculina*, not specifically identifiable, was found, and some indeterminate fish vertebrae.

III. ENVIRONMENT

Regional investigations have not yet reached the stage where it is possible to determine whether conditions of sedimentation were lacustrine or estuarine. Since my preliminary note (Ludbrook, 1953) was published Dr. R. W. Fair-

bridge has suggested to me that the microfaunal assemblage is one which would naturally inhabit an extensive gulf or estuary reaching Lake Eyre via Lake Torrens from the head of Spencer's Gulf during the high sea level phases of the Pleistocene. While this is certainly feasible, freshwater lake deposits now represented by indurated oolitic ostracode limestones, similar to the dolomitic limestone in which the borings ceased, have been found in widely separated localities in the west of South Australia. Whether the lacustrine environment persisted at Lake Eyre, increasing salinity providing a favourable milieu for brackish water organisms which had been introduced by birds, or whether freshwater lakes were transformed during part of the Pleistocene into the estuary suggested by Dr. Fairbridge can be determined only by observations made on a regional scale.*

IV. ACKNOWLEDGMENTS

I am indebted to the Petrology Section, Department of Mines, for identification of the saponite and beidellite-nontronite minerals, to Dr. H. B. S. Womersley for placing specimens of *Characeae* belonging to the Botany Department, University of Adelaide, at my disposal, to Mr. B. C. Cotton for allowing me to examine mollusca in the South Australian Museum, and to Dr. Rhodes Fairbridge for drawing my attention to the possible conditions of deposition

V. FAUNA

FORAMINIFERA

Family NONIONIDAE.

Genus ELPHIDIUM Montfort, 1808.

Type species *Nautilus macellus* Fichtel & Moll.

(?) Elphidium advenum (Cushman).

pl. 1, fig. 9

For early synonymy see Cushman, 1939, U.S.G.S. Prof. Paper 191, p. 60; Bermudez, 1949, Cush. Lab. Foram. Res. Spec. Pub., 25, p. 167.

Elphidium advenum (Cushman), 1944, Cushman Lab. Foram. Resp. Spec. Pub., 12, p. 26, pl. 3, fig. 36.

Elphidium advenum (Cushman) Howchin & Parr, 1938, Trans. Roy. Soc. S. Aust., 62 (2), p. 299.

Elphidium advenum Cushman, Parr, 1943, Mal. Soc. S. Aust. Pub. 3, p. 20; 1950, Journ. Roy. Soc. W. Aust., 34, p. 72.

Material—One worn specimen, sample F173/53 Bore 1, 0ft. 0in.-0ft. 6in.

The calcified condition of the single specimen renders identification very doubtful. Its occurrence only in the surface sample of Bore 1 suggests that the species may have been introduced by birds and had no continuous existence in the area. On the other hand, it is recorded as occurring frequently in the late Pleistocene "*Arca*" horizon of Peppermint Grove (Parr, 1950).

* Since the above was submitted for publication, Mr. V. R. Rao has shown me a paper by Jacob, Sastry and Sastri on the Microfossils of the Impure Gypsum from the Jamsar Mine, Bikaner, published in the Proceedings of the Symposium on the Rajputana Desert (Bulletin of the National Institute of Sciences of India 1, September, 1952). The authors record (p. 68) the occurrence of "*Chara*, Ostracoda and a few small shallow water marine Foraminifera in the Intertrappean beds of Rajahmundry" which they believe to be of Eocene age, and attribute the presence of *Chara* to its being transported from fresh-water areas. In a supplementary note (p. 69) they record the discovery of the foraminifer *Discorbis*, probably blown in by the wind, with shells of *Vivipara bengalensis* (Lam.) and *Chara* "fruits" in gypsum deposits at Siasar.

Recently, an assemblage identical, except for minor specific differences, to that in the Lake Eyre clays has been recovered from surface silty sands in swamps bordering Lake Alexandrina. Here also *Chara* is associated with *Coxiella*, ostracodes, "*Rotalia*" *beccarii* var. *tepida* and *Elphidium advenum*.

Howchin (1901, p. 9) postulated dispersal by birds of the two species of *Elphidium* which he discovered in the silt at Yorketown Lagoon.*

Genus NONION Montfort, 1808.

Type species *Nautilus incrassatus* Fichtel & Moll.

(?) Nonion scapha (Fichtel & Moll)

pl. 1, fig. 10.

For synonymy see Cushman, 1939, U.S.G.S. Prof. Paper, 191, p. 20.
Nonion scapha Fichtel & Moll. Parr, 1943, Mal. Soc. S. Aust. Pub. 2, p. 20.
Nonion scaphum (Fichtel & Moll). Cushman, 1946, Cush. Lab. Foram. Res. Spec. Pub., 17, p. 14.

One specimen, sample F177/53.

Bore 1. 6ft. 6in.-7ft. 9in.

As the test is coated with thin calcite and the aperture obscured, identification of this species is tentative only.

Family ANOMALINIDAE

Genus CIBICIDES Montfort, 1808.

Type species *Cibicides refulgens* Montfort.

Cibicides refulgens Montfort

pl. 1, figs. 11, 12.

For early synonymy see Cushman, 1931. U.S. Nat. Mus. Bull., 104, pt. 8, p. 116, *Cibicides refulgens* Montfort, Cushman & Todd, 1945, Cush. Lab. Foram. Res. Spec. Pub., 15, p. 70. Cushman & Gray, 1946, *id.* Spec. Pub., 19, p. pl. 8, figs. 15-17, Cushman & Todd, 1947, *id.* Spec. Pub., 21, p. 23, pl. 4, fig. 7. Chapman & Parr, 1935. Journ. Roy. Soc. S. Aust., 21, p. 3, Crespin, 1943, Min. Res. Sur. Bull., 9 (Pal. Ser. 4), p. 78 (mimeographed). Parr. 1950, Journ. Roy. Soc. W. Aust., 34, p. 71.

Material—One specimen, Sample F.

Borehole 4, 3ft. 6in.-12ft. 0in.

The specimen recovered is small and well preserved and typical of the species. Although its occurrence also suggests fortuitous introduction, it was recorded as common in the late Pleistocene "*Arca*" horizon, Peppermint Grove.

Family ROTALIIDAE.

Genus ROTALIA Lamarck, 1804.

Type species *Rotalia trochidiformis* Lamarck.

"Rotalia" beccarii Linné cf. var. **tepida** Cushman,

pl. 1, figs. 13, 14, 15

Rotalia beccarii (Linné) var. *tepida* Cushman, 1926, Carnegie Inst., Washington, Pub. 344, p. 79, pl. 1. D. K. Palmer, 1945, Bull. Amer. Pal., 29 (115), p. 60 (*fide* Bermudez); Bermudez, 1949, Cush. Lab. Foram. Res. Spec. Pub., 25, p. 234.
Streblus beccarii (Linné) var. cf. *tepida* (Cushman). Parr, 1950, Journ. Roy. Soc. W. Aust., 34, p. 22.

Material—Calcified specimens, as many as 49 in one sample, from almost all but 5 samples from Boreholes 1 and 4; numerous (over 100) well-preserved specimens from matrix of upper (*Coxiella*) shell bed.

The occurrence of this species in almost every sample including the sulphur bed suggests that its introduction has not been completely fortuitous. Two possibilities present themselves: the first, that widespread estuarine conditions during the late Pleistocene enabled the species to spread towards Lake Eyre from the head of Spencer's Gulf, the second, that the variety has been introduced by birds or by winds into shallow saline lakes in the late Pleistocene, and finding a favourable habitat rapidly established itself.

* The uppermost eighteen inches of gypseous mud in Peesey's Swamp, Yorke Peninsula, carries a brackish-water microfauna dominated by *Elphidium advenum* in association with the gastropoda *Coxiella confusa* Smith, *Batillaria* (*Batillariella*) *estuarina* (Tate) and ostracodes. This fauna is distinct from that of the underlying travertine-capped, loosely consolidated Recent shelly sandstone and limestone which carries abundant marine littoral mollusca and foraminifera.

All specimens show abundant evidence of environmental influence. As compared with marine examples of the species, the tests are small and variable in shape. Those recovered from the clays of Borehole 1 and Borehole 4 are all heavily calcified. Very few showed the umbilical plug generally characteristic of the species.

All the Lake Eyre specimens appear, so far as one can determine in the absence of authentic topotypes for comparison, to be close to the variety *lepida* described by Cushman (1926, p. 79) from shallow and stagnant water at Porto Rico. It has been recorded and illustrated by Bermudez (1949, p. 234, pl. 15, figs. 49-51) associated with a shallow water molluscan fauna from the Upper Miocene of Las Salinas Formation Dominican Republic and by Parr from the "*Arca*" horizon, Peppermint Grove.

The two specimens figured show the degree of variation presented by the Lake Eyre specimens. One (pl. 1, fig. 15) is typical of the calcified tests obtained from the clays of the bores. The other (pl. 1, figs. 13, 14) is a somewhat extreme example of the form which occurs numerously in the *Coxiella* bed. It is characterized by its small, fairly thin test, only slightly limbate sutures and absence of umbilical plug. The astral lobe, if developed at all, is frequently broken and not preserved.

MOLLUSCA.

Class **PELECYPODA**
Superfamily SPHAEREACEA.
Family CORBICULIDAE.
Genus CORBICULINA Dall, 1903.

Corbiculina Dall, 1903, Proc. Biol. Soc. Washington, **16**, p. 6.

Type species (monotypy) *Corbicula angasi* Prime.

Corbiculina sp. indet.

Material—One broken specimen, sample F172/53.

A fragment only of the hinge portion of a juvenile shell was collected from the upper shell bed. In view of extreme intraspecific variation in this genus, it is impossible to decide whether it is the Recent species *Corbiculina desolata* (Tate) or not.

Class **GASTROPODA**
Superfamily RISSOACEA.
Family ASSIMINEIDAE.
Genus COXIELLA Smith, 1894.

Coxiella Smith, 1894, Proc. Malac. Soc. **1**, p. 98.
(*Blanfordia* Cox, 1868, Mon. Aust. Land Shells, p. 94, *non* Menke.)
(*Coxielladda* Iredale & Whitley, 1938, S. Aust. Nat., **18** (3), p. 66.)
(*Blandfordia* Tate 1894, Trans. Roy. Soc. S. Aust., **18**, p. 196, lapsus calami for *Blanfordia*.)

Type species (monotypy) *Truncatella striatula* Menke.

Coxiella gilesi (Angas).
pl. 1, fig. 1.

Paludinella gilesi Angas, 1877, Proc. Zool. Soc., March, p. 169, pl. 26, fig. 2.
Paludinella gilesii Angas. Tate & Brazier, 1882, Proc. Linn. Soc. N.S.W., 6, p. 564.
Blandfordia stirlingi Tate, 1894, Trans. Roy. Soc. S. Aust., 18, p. 196
Coxielladda gilesi Iredale & Whitley, 1938, S. Aust. Nat., **18** (3), p. 66.
Coxielladda gilesi Angas. Cotton, 1942, Trans. Roy. Soc. S. Aust., **66** (2), p. 129.

Description—Shell thin, globose-turbinate, perforate, with a rather low spire, apparently orange or flesh-coloured, but almost always bleached white.

Apex subacute, flattened at the origin, protoconch of 1½ flatly convex almost smooth turns constricted at the suture, followed by 4½ roundly convex whorls fairly rapidly increasing in size, arcuate in profile, sculptured with fine, somewhat irregular, transverse growth strial. Sutures impressed, strongly marked. Body whorl large, about three-quarters total height of shell. Umbilicus narrow, generally almost concealed by the expansion of the aperture over the columella.

Aperture subovate, roundly angulate posteriorly and rounded anteriorly, peristome entire, everted over the columella, parietal callus thin and frequently broken.

Dimensions of Figured Specimen—Height 5·3; width 4; height of body whorl 4; height of aperture 3·7; width of aperture 2 mm.

Type Locality—Lake Eyre.

Holotype—British Museum.

Material—Innumerable specimens, upper shell bed, Lake Eyre North.

Distribution—Lake Eyre, Lake Callabonna.

Observations—There is no evidence that this shell has survived desiccation of the area. Although both Angas, who described the Lake Eyre species, and Tate, who described its Lake Callabonna counterpart, found one specimen retaining the original colour, all the specimens seen by the writer have been bleached white.

The species is closely related morphologically and in apparent habitat to *Coxiella confusa* (Smith) found sometimes in enormous numbers in submarginal lagoons and salt lakes in the southern part of the State. The genus is euryhaline, with a very wide range of salinity tolerance covering from freshwater to waters more saline than the sea, its preference apparently being for the latter.

Iredale and Whitley (1938, p. 66) introduced without diagnosis the name *Coxielladda* for *Paludina* (*sic*) *gilesi* Angas. On morphological grounds, it is impossible to select diagnostic generic characters to justify the genus. Intraspecific variation in *Coxiella* is considerable, particularly in the height of the spire, and to give this the status of generic diagnosis (Cotton 1942, p. 129) can hardly be supported. Neanic specimens of *Coxiella confusa* bear a very close resemblance to adults of *Coxiella gilesi*.

The species described by Tate (1894, p. 196) as *Blandfordia stirlingi* is almost certainly conspecific with the present species, although only a statistical analysis of the very numerous examples from the two areas can establish the fact. Tate (l.c.p.195) noted the relationship between the southern *Coxiella confusa* (= *Blanfordia striatula* Tate *non* Menke). Increasingly saline conditions in Lake Eyre doubtless provided a favourable milieu for the development of innumerable Coxiellas. In this environment *Pontocypris attenuata* could also survive and "*Rotalia*" *beccarii* although inadequately nourished, maintain a foothold.

The affinities of the genus *Coxiella* are ill-defined. Wenz (1938, p. 582) places it in the Tomichiinae, subfamily of the *Truncatellidae* to which it appears to the writer to be not closely related. It is here placed in the *Assimineidae*: it seems to be close to *Paludinella* in which *gilesi* was originally placed by Angas.

OSTRACODA.

Family CYPRIDAE.

Genus CYPRIS Muller.

Type species *Cypris pubera* Muller.

(?) **Cypris** sp.

pl. 1, figs. 7, 8.

Description—Carapace viewed laterally, broadly reniform, greatest height in the middle, equal to more than half the length. Anterior extremity gently arcuate, proterior extremity flatly rounded; dorsal margin arched, highest in front of the middle ventral margin sinuated in the middle valves unequal, right slightly larger than left and overlapping it in part of the middle of the dorsal margin.

Surface when well preserved sculptures with a fine reticulate pattern. Adductor muscle scars four in the middle of the shell, frequently visible from the outside.

Dimensions—Length 0·6 mm.; width 0·36 mm.

Observations—Although it is generally obscured by a coating of calcite which may be very thick, the reticulate sculpture readily characterizes the species which I have not so far been able to identify.

Genus PONTOCYPRIS G. O. Sars, 1866.

Type species *Pontocypris trigonella* G. O. Sars.

Pontocypris attenuata G. S. Brady.

pl. 3, figs. 5, 6.

Pontocypris attenuata Brady, 1868, Ann. Mag. Nat. Hist., ser 4, 2, p. 179, pl. 4, figs. 11-14; Brady, 1880, Chall. Rep. Zool., 1 (3), p. 38, pl. 15, figs. 1a-d; Brady, 1890, Trans. Roy. Soc. Edin., 35, p. 491, pl. 1, figs. 3, 4; Chapman, 1902, Journ. Linn. Soc. Lond., 28, p. 419; Chapman, 1910, *id.*, 30, p. 427; Chapman, 1919, Austr. Abstract, Exped., Ser. C. 5 (7), p. 17; Chapman, 1941, Trans. Roy. Soc. S. Aust., 65 (2), p. 194, pl. 9, fig. 8.

Material—45 single valves.

Observations—This is a shallow water Indo-Pacific and Australian species which has been recorded twice by Chapman from deep water, first at 1,215 fathoms at Funafuti and secondly from 505 fathoms off South-Eastern Australia. With the exception of one specimen from 16ft. 4in. to 18ft. 8in. in Borehole No. 1, all the present examples were found either in the matrix of the upper shell bed or in the clay beneath the shell bed. This would indicate that the species was of late sporadic introduction and survived only in saline water.

No undamaged pair of valves was obtained. Many of the single valves, both adult and juvenile, one of which is figured (pl. 1, fig. 6) still retained the conspicuous posterior spine which Brady (1890, p. 491) and Chapman (1941, p. 194) have noted. One specimen bears an additional small anterior spine. Either the spines are an inconstant feature, or they are easily broken from the carapace and not preserved.

VI. FLORA

1. Oogonia of Characeae.

Nearly all samples contain oogonia of *Chara* probably belonging to more than one species. These could not be identified as belonging to any described species living in South Australia. The three shapes illustrated (pl. 3, figs. 2, 3, 4) may possibly represent three species.

2. Leaves.

From the matrix of the *Coxiella* shell bed some small, elongate, rather thick leaves, possibly of chenopodiaceous plants were recovered. These had probably been blown in by the wind and deposited with the shells.

VII. DISTRIBUTION

The distribution of the microfossils and the number of specimens recovered from washing about 200 gms. of each sample are shown in the distribution table.

VIII. REFERENCES

ANGAS, G. F., 1877. Descriptions of a new Species of *Bulimus* from Western Australia and of a *Paludinella* from Lake Eyre, South Australia, Proc. Zool. Soc. Lond., March, 1877, pp. 169-170, pl. 26, figs. 1-2.

BERMUDEZ, P. J., 1949. Tertiary Smaller Foraminifera of the Dominican Republic, Cush. Lab. Foram. Res. Spec. Pub. No. 25, 332 pp., 26 pls.

BRADY, G. S., 1868. Contributions to the Study of the Entomostraca, No. 2 Marine Ostracoda from the Mauritius, Ann. Mag. Nat. Hist., ser. 4, 2, pp. 178-184, pls. 12-13.

Brady, G. S., 1880. Report on the Ostracoda dredged by H.M.S. Challenger during the years 1873-1876, Rep. Sci. Res. Chall. Zool., 1 (3), pp. 1-184, pls. 1-44.

Brady, G. S., 1890. On Ostracoda collected by H. B. Brady, Esq., LL.D., F.R.S., in the South Sea Islands, Trans. Roy. Soc. Edinburgh, 35 (2), 14, pp. 489-525, pls. 1-4

Chapman, F., 1902. On some Ostracoda from Funafuti. Journ. Linn. Soc. Lond., 28, pp. 417-433, pl. 37.

Chapman, F., 1910. On the Foraminifera and Ostracoda from Soundings (chiefly deep-water) collected round Funafuti by H.M.S. Penguin, Journ. Linn. Soc. Lond., 30, pp. 388-444, pls. 54-57.

Chapman, F., 1919. Ostracoda, Australasian Antarctic Expedition, 1911-1914, Sci. Rep. Ser. C. Zool. & Bot., 5 (7), 48 pp., 2 pls.

Chapman, F., 1941. Report on the Foraminiferal Soundings and Dredgings of the F.I.S. "Endeavour" along the Continental Shelf of the South-east Coast of Australia, Trans. Roy. Soc. S. Aust., 65 (2), pp. 145-211, pls. 7-9.

Chapman, F., and Parr, W. J., 1935. Foraminifera and Ostracoda from Soundings made by the trawler "Bonthorpe" in the Great Australian Bight. Journ. Roy. Soc. W. Aust., 21, Art. 1, pp. 1-7, pl. 1

Cotton, B. C., 1942. Australian Gastropoda of the Families Hydrobiidae Assimineidae and Acmeidae, Trans. Roy. Soc. S. Aust., 66 (2), pp. 124-129, pls. 4, 5.

Cotton, B. C., 1943. More Australian Freshwater Shells, Trans. Roy. Soc. S. Aust., 67 (1), pp. 143-148, pls. 14-19.

Cox, J. C., 1868. A Monograph of Australian Land Shells, William Maddock, Sydney.

Crespin, I., 1943. The Stratigraphy of the Tertiary Marine Rocks in Gippsland, Victoria. Dept. Supp. & Ship. Min. Res. Surv. Bull. 9 (Pal. Ser. 4) (mimeographed).

Cushman, J. A., 1926. Recent Foraminifera from Porto Rico, Pub. 344, Carnegie Inst., Washington, pp. 73-84, pl. 1.

Cushman, J. A., 1939. A Monograph of the Foraminiferal Family Nonionidae, U.S. Dept. Interior, Geol. Surv. Prof. Pap., 191, 100 pp. 20 pls.

Cushman, J. A., 1944. Foraminifera from the Shallow Water of the New England Coast, Cush. Lab. Foram. Res. Spec. Pub. No. 12, 37 pp., 4 pls.

Cushman, J. A., 1946. The Species of Foraminifera named and figured by Fichtel and Moll in 1798 and 1803, Cush. Lab. Foram. Res. Spec. Pub. 17, 16 pp., 4 pls.

Cushman, J. A., and Gray, H. B., 1946. A Foraminiferal Fauna from the Pliocene of Timms Point, California. Cush. Lab. Foram. Res. Spec. Pub. 19, 46 pp., 18 pls

Cushman, J. A., and Todd, R., 1945. Miocene Foraminifera from Buff Bay, Jamaica, Cush. Lab. Foram. Res. Spec. Pub. 15, 73 pp., 12 pls.

Cushman, J. A., and Todd, Ruth, 1947. Foraminifera from the Coast of Washington, Cush. Lab. Foram. Res. Spec. Pub., 21, 23 pp., 4 pls.

Dall, W. H., 1903. Review of the Classification of the Cyrenacea, Proc. Biol. Soc. Washington, 16, pp. 5-8.

Fischer, P., 1887. Manuel de Conchyliologie. Paris, 1,369 pp.

Howchin, W., 1901. Suggestions on the Origin of the Salt Lagoons of Southern Yorke Peninsula, Trans. Roy. Soc. S. Aust., 25 (1), pp. 1-9.

Howchin, W., and Parr, W., 1938. Notes on the Geological Features and Foraminiferal Fauna of the Metropolitan Abattoirs Bore, Adelaide, Trans. Roy. Soc. S. Aust., 62 (2), pp. 287-317, pls. 15-19.

Iredale, T., and Whitley, G. P., 1938. The Fluvifaunule of Australia, S. Aust. Nat. 18 (3), pp. 64-68.

Ludbrook, N. H., 1953. Foraminifera in Sub-Recent Sediments at Lake Eyre, South Australia. Aust. Journ. Sci. 16 (3), pp. 108-109.

Madigan, C. T., 1932. The Geology of the Eastern Macdonnell Ranges, Central Australia Trans. Roy. Soc. S. Aust., 56, pp. 71-117.

Parr, W. J., 1943. A Systematic List of the Echinodermata, Foraminifera, Hydroida, Brachiopoda of Southern Australia, ed. B. C. Cotton and F. K. Godfrey. Mal. Soc. S. Aust. Pub., 3, pp. 12-24.

Parr, W. J., 1950. Foraminifera. In Fairbridge, R.W. The Geology and Geomorphology of Point Peron, Western Australia, Journ. Roy. Soc. W. Aust. Inc., 34, Appendix II, pp. 70-72.

Reid, C., and Groves, J., 1921. The Charophyta of the Lower Headon Beds of Hordle (Hordwell) Cliffs (South Hampshire), Quart. Journ. Geol. Soc., 77 (3), pp. 175-192, pls. 4-6.

Smith, E. A., 1891. On the Land Shells of Western Australia, Proc. Malac. Soc., I, pp. 84-99, pl. 7.

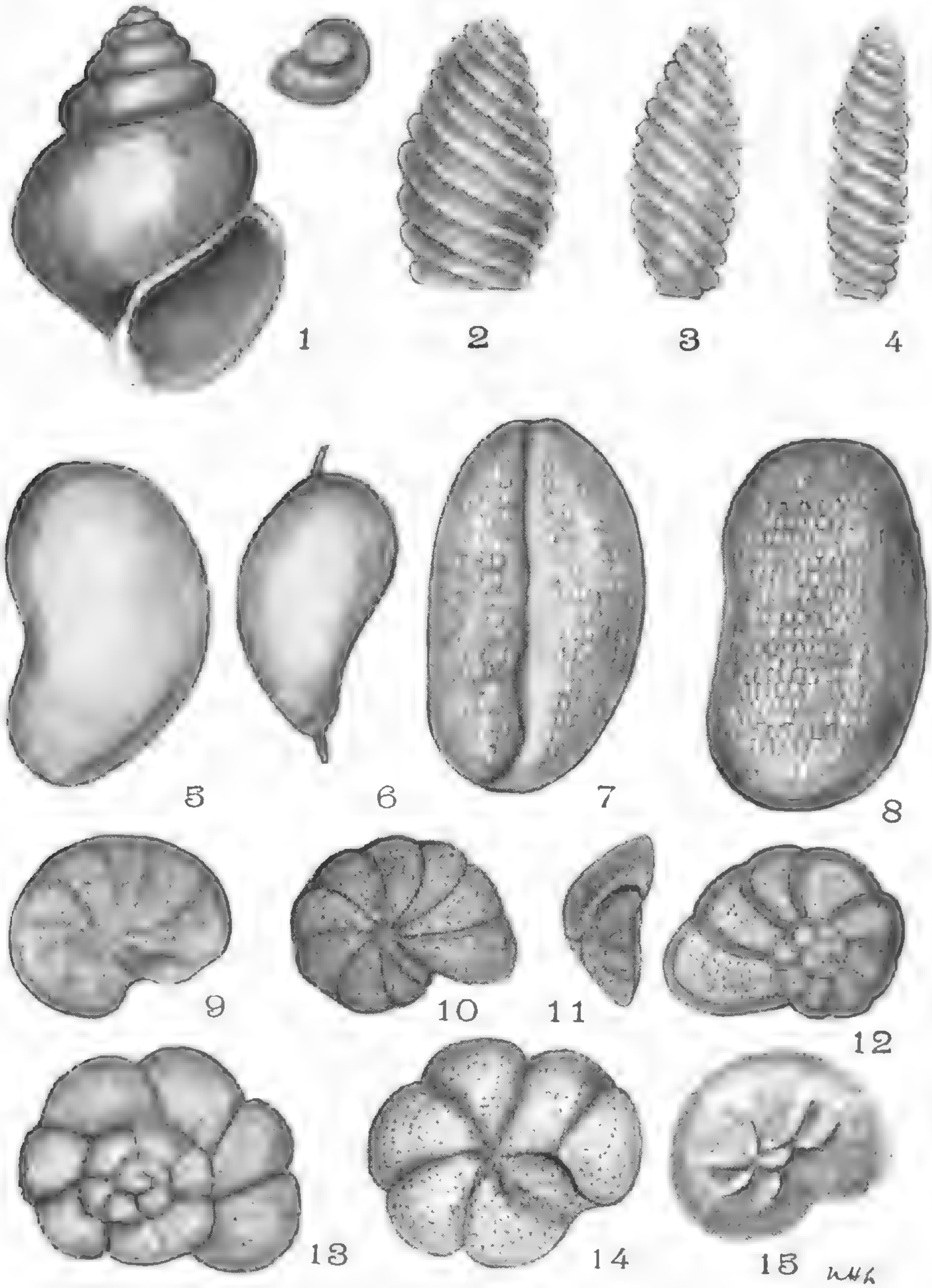
Tate, R., 1894. Notes on the Organic Remains of the Osseous Clays at Lake Callabonna, Trans. Roy. Soc. S. Aust., 18, pp. 195-196.

Tate, R., and Brazier, J., 1882. Check List of the Fresh-water Shells of Australia, Proc. Linn. Soc. N.S.W., 6 (3), pp. 552-569.

Wenz, W., 1938. Gastropoda, Handb. Palaozool., 2, pp. 480-720.

EXPLANATION OF PLATE

Fig. 1.—*Coxiella gilesi* (Angas), x 10; protoconch, x 37.
Fig. 2.—*Chara* sp. 1, oogonium, x 35.
Fig. 3.—*Chara* sp. 2 (?), oogonium, x 35.
Fig. 4.—*Chara* sp. 3 (?), oogonium, x 40.
Fig. 5.—*Pontocypris attenuata* Brady, adult left valve without spines, x 65.
Fig. 6.—*Pontocypris attenuata* Brady, juvenile left valve with anterior and posterior spines, x 65.
Fig. 7.—*Cypris* sp., both valves, lateral view, x 80.
Fig. 8.—*Cypris* sp., left valve, x 85.
Fig. 9.—(?) *Elphidium advenum* (Cushman), x 110.
Fig. 10.—(?) *Nonion scapha* (Fichtel & Moll), x 85.
Fig. 11.—*Cibicides refulgens* Montfort, apertural view, x 180.
Fig. 12.—*Cibicides refulgens* Montfort, dorsal view, x 180.
Fig. 13.—*Rotalia beccarii* (Linné) var. *tepida* Cushman, extreme form, dorsal view, x 80.
Fig. 14.—*Rotalia beccarii* (Linné) var. *tepida* Cushman, extreme form, ventral view, x 80.
Fig. 15.—*Rotalia beccarii* (Linné) var. *tepida* Cushman, calcified specimen, typical of Lake Eyre sediments, x 80.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
NHL

AN ALTERNATIVE CALCULATION FOR POTENTIAL EVAPOTRANSPIRATION

BY *B. M. TUCKER*

Summary

An empirical method for the approximate calculation of potential evapotranspiration has been developed for application to stations where maximum and minimum temperatures are recorded, but no humidity data are available. From the difference between saturated water vapour pressures at the normal monthly mean and minimum temperatures an estimate of standard tank evaporation E to the power 0•75 can be obtained. This value may then be used in Prescott's formulae for potential evapotranspiration. The method may also be used as a means of extrapolation from stations which keep humidity records to those which do not.

AN ALTERNATIVE CALCULATION FOR POTENTIAL EVAPOTRANSPIRATION

By B. M. Tucker*

[Read 12 May 1955]

SUMMARY

An empirical method for the approximate calculation of potential evapotranspiration has been developed for application to stations where maximum and minimum temperatures are recorded, but no humidity data are available. From the difference between saturated water vapour pressures at the normal monthly mean and minimum temperatures an estimate of standard tank evaporation E to the power 0·75 can be obtained. This value may then be used in Prescott's formulae for potential evapotranspiration. The method may also be used as a means of extrapolation from stations which keep humidity records to those which do not.

INTRODUCTION

An analysis of the water economy of a landscape is valuable for an understanding of the role of rainfall in plant ecology and soil formation. A general procedure for such an analysis using the balance between rainfall and evapotranspiration was proposed by Thornthwaite (1948) and has been elaborated by Prescott *et al.* (1952). The first step in this analysis is the estimation of potential evapotranspiration—the amount of evaporation and transpiration which can occur when water is 'readily available'. Thornthwaite used a compound-power function of normal monthly mean temperature for this estimation, whereas Prescott *et al.* used a power function of atmospheric saturation deficit which can be calculated from normal monthly mean temperatures and relative humidities. Both of these functions are based on the comparison of measured evapotranspirations with climatological records.

Atmospheric humidity is recorded less frequently than air temperatures and this paper examines a method giving fair values for potential evapotranspiration for places where only maximum and minimum temperatures are recorded. One such method has been proposed by Halstead (1951) and has been discussed by Gentilli (1953). In Halstead's method potential evapotranspiration is calculated from normal monthly maximum and minimum temperatures which are taken as equal to the temperatures of the transpiring surfaces and the dewpoint of the air respectively.

SYMBOLS

- E estimated or observed normal monthly evaporations from a water surface; specifically from a standard Australian tank (in inches).
- E_t potential evapotranspiration (in inches).
- E_{day} observed tank evaporation calculated for a day of 12 hours possible sunshine (in inches).
- N hours of possible sunshine in a month (dependent on latitude and month).
- K environment factor of Prescott *et al.* (1952).
- u wind velocity.
- h normal monthly relative humidity at 9 a.m.

* C.S.I.R.O., Division of Soils, Adelaide.

e	saturated water vapour pressure (in inches of mercury) with subscripts—
e_a	at normal monthly mean air temperature.
e_m	at normal monthly minimum air temperature.
e_d	at normal monthly dewpoint.
e_s	at temperature of evaporating surface.

DEVELOPMENT OF THE METHOD

The method for calculating evaporation used by Prescott (1938) and based on an estimate of atmospheric saturation deficit is derived from the equation of Dalton which may be put into a form applicable to a water surface

$$E = (e_s - e_d)\,F(u).$$

This equation assumes other factors to be fixed or not limiting. By ignoring the variations in wind velocity and assuming that normal monthly temperatures are adequate for determining average vapour pressure differences, this equation may be replaced by the approximation

$$E \simeq k\,(e_s - e_d).$$

The temperature of the water surface is usually unknown so that it is assumed to be equal to the air temperature—

$$E \simeq k(e_a - e_d).$$

The difference $e_a - e_d$ is the atmospheric saturation deficit. To use this approximation for an empirical determination of k it is necessary to obtain mean values of e_d. It has been observed that the relative humidity recorded at 9 a.m. is on the average close to the mean for the day, and Prescott uses this value to obtain an estimate e_d' of e_d from e_a

$$e_d' = h.e_a.$$

His formula for calculating evaporation is then

$$E \simeq k_1(e_a - e_d') = k_1.e_a(1 - h),$$

and the empirical value of k_1 is 21·2 for months of 30 days (Prescott, 1938). Prescott (1949) has shown that potential evapotranspiration can be calculated from the monthly evaporation from a water surface by the formula

$$E_t = K.E^m.$$

The power m is given a standard value of 0·75 and since $21{\cdot}2^{0.75} = 10$ his formula for calculating potential evapotranspiration from temperature and humidity records is

$$E_t = 10.K\,\{e_a(1 - h)\}^{0.75}.$$

Halstead assumed that 'the minimum air temperature reaches the dewpoint temperature each night'. This is not true for all localities on all occasions, but it has been observed that 'there is a considerable degree of parallelism between the mean values of dewpoint and minimum temperature' (Bilham, 1938). On the basis of this observation, it may be expected that the difference $(e_a - e_m)$ will serve as an approximation for saturation deficit when no humidity records are available.

Comparison of Estimates of Saturation Deficit

The best estimates of saturation deficit $(e_a - e_d)$ given by Foley (1945, table V) are based on hourly air temperatures and relative humidities. The two approximate estimates $(e_a - e_d')$ and $(e_a - e_m)$ have been compared with the best estimate for the same stations and periods used by Foley. On the whole the twelve pairs of monthly values for each station fitted closely to power functions of the forms

$$e_a - e_m = r\,(e_a - e_d)^p \text{ and}$$
$$e_a - e_d' = r'\,(e_a - e_d)^{p'}$$

where p ranged from 0·6 to 0·9 and p' from 1·1 to 1·6. Generally, $(e_a - e_m)$ underestimates $(e_a - e_d)$ in the summer months, whereas $(e_a - e_d')$ overesti-

mates it. The data from 19 years' records at Melbourne are plotted in Figure 1. The ideal relationship of $(e_a - e_m)$ or $(e_a - e_d')$ equal to $(e_a - e_d)$ is shown by the broken line. The regression lines calculated for the logarithms of the estimates are shown in the figure as

$$e_a - e_m = 0{\cdot}67\ (e_a - e_d)^{0.82} \text{ and}$$
$$e_a - e_d' = 1{\cdot}8\ (e_a - e_d)^{1.5}.$$

A statistical assessment of the two approximate estimates of saturation deficit showed that for Sydney, Hobart and Perth $(e_a - e_d')$ was better than $(e_a - e_m)$ as an estimate of $(e_a - e_d)$, that for Adelaide and Melbourne neither was significantly better and that for Brisbane $(e_a - e_m)$ was better than $(e_a - e_d')$. The estimate $(e_a - e_m)$ is therefore not as good as $(e_a - e_d')$ as an estimate of saturation deficit, but it is nevertheless sufficiently closely related to justify a further examination of its relation to measured evaporation.

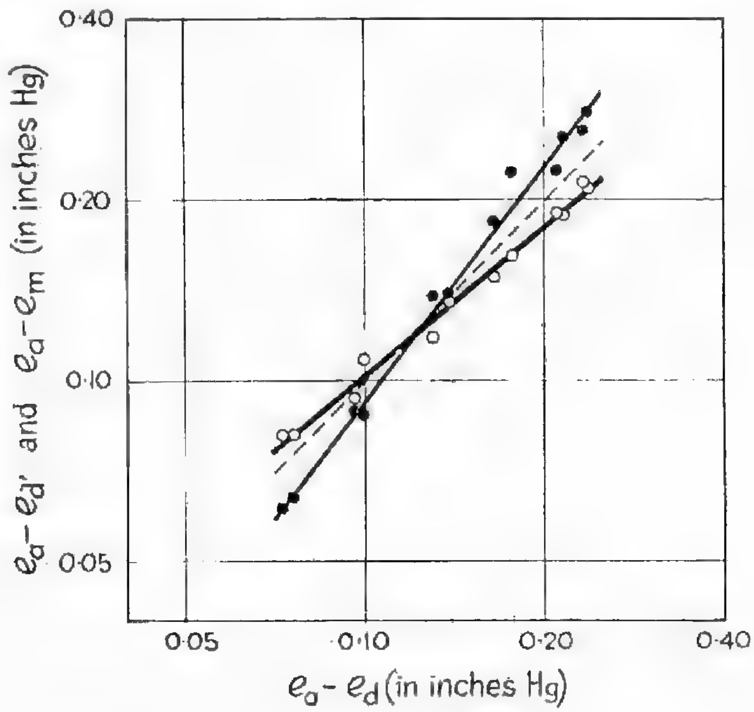


Fig. 1—Comparison of estimates of normal monthly saturation deficit at Melbourne.

Open circles for $(e_a - e_m)$. Black circles for $(e_a - e_d')$.

The Relation Between E and $(e_a - e_m)$

For this purpose the observed normal monthly values of tank evaporation E as given in the monthly summaries of the Meteorological Branch to the end of 1952 were converted to the corresponding values E_{day} for a standard day of 12 hours possible sunshine by the formula—

$$E_{day} = 12.E/N.$$

The values of N for each month and each latitude to the nearest five degrees were calculated from data in the Smithsonian Meteorological Tables. This correction for length of day has been used by both Thornthwaite and Halstead since transpiration and evaporation occur largely during the day: in the present work the correction brings the relation between evaporation and $(e_a - e_m)$ into a form similar to that between $(e_a - e_d)$ and $(e_a - e_m)$, that is, the powers p and n are approximately equal.

A graphical examination of the records for a number of Australian stations showed that for each station the relation between the twelve pairs of monthly values could be expressed as a power function

$$(E_{day})^n = c\ (e_a - e_m).$$

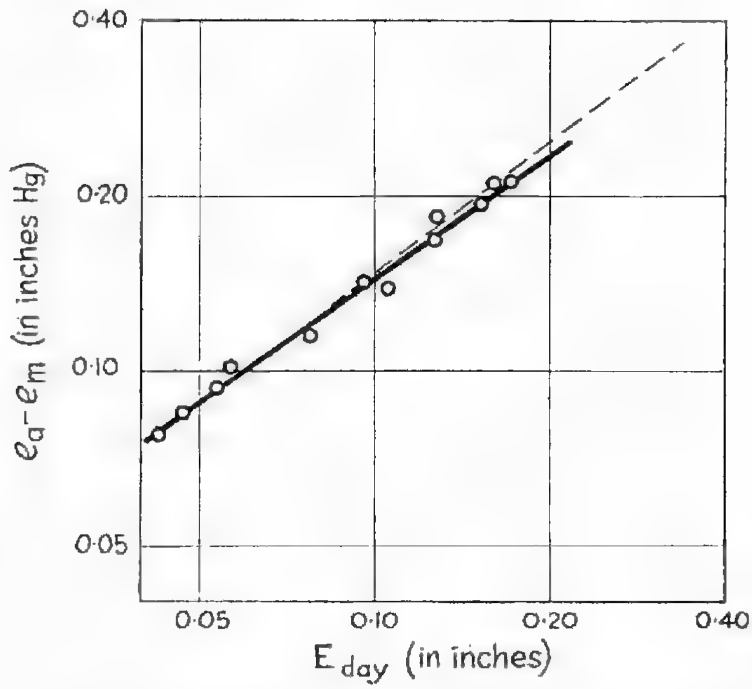


Fig. 2.—The relation between standard day evaporation and crude saturation deficit based on normal monthly minimum temperatures for Melbourne.

This type of relation, with n less than unity, was anticipated from the relation between $(e_a - e_d)$ and $(e_a - e_m)$. The data for Melbourne are plotted in Figure 2. The full line is

$$E_{day}^{0.71} = 1 \cdot 35(e_a - e_m),$$

based on the regression line

$$\log\ (e_a - e_m) = 0 \cdot 712 \log E_{day} - 0 \cdot 130.$$

The broken line is

$$E_{day}^{0.75} = 1 \cdot 2\ (e_a - e_m) \qquad \text{[see below]}$$

The values of n and c varied between stations like p and r. The mean value of n for these stations came to 0·76 which is a useful coincidence with the power m of Prescott. We may therefore write

$$E_{day}^{0.75} \simeq c'\ (e_a - e_m)$$

as the general form of the empirical relationship. The means for the twelve actual monthly values of c' show considerable variations between stations like the analogous coefficient ($k_1^{0.75}$: standard value 10) used in Prescott's formula for potential evapotranspiration. The means of the twelve monthly values of c' were calculated from the records of 42 stations taken from the monthly summaries of the Meteorological Branch, from Prescott (1943) and Shepherd (1949). The average of the 42 means was 1·18 with a standard deviation of 0·21, and accepting this average as the best available value of c' we may write

$$E_{day}^{0.75} \simeq 1 \cdot 2\ (e_a - e_m)$$

and for monthly values

$$(12\ E/N)^{0.75} \simeq 1 \cdot 2\ (e_a - e_m)$$
$$\text{or } E^{0.75} \sim 1 \cdot 2 f\ (e_a - e_m)$$

where $f = (N/12)^{0.75}$. Table 1 gives values of f for each month and latitude to the nearest 5 degrees appropriate to Australia. Using Prescott's relation between evaporation and potential evapotranspiration we obtain a working formula

$$E_t \simeq 1{\cdot}2.K f.(e_a - e_m).$$

TABLE 1.
Values of $f = (N/12)^{0.75}$

Latitude S	15	20	25	30	35	40	45
January	13·9	14·1	14·4	14·6	14·9	15·2	15·7
February	12·7	12·8	12·9	13·1	13·3	13·5	13·7
March	13·3	13·3	13·3	13·3	13·4	13·5	13·5
April	12·6	12·5	12·4	12·3	12·2	12·0	11·8
May	12·6	12·4	12·2	12·0	11·7	11·4	11·0
June	12·2	12·0	11·7	11·4	11·0	10·6	10·2
July	12·0	12·3	12·1	11·8	11·5	11·1	10·7
August	12·8	12·7	12·5	12·3	12·2	11·9	11·7
September	12·8	12·8	12·8	12·7	12·7	12·6	12·6
October	13·5	13·6	13·7	13·8	13·9	14·0	14·2
November	13·5	13·6	13·9	14·1	14·3	14·6	15·0
December	14·0	14·2	14·5	14·8	15·3	15·5	16·0

Calculated from data given in Smithsonian Meteorological Tables 6th revised edition.

APPLICATIONS OF THE METHOD

The calculated values of $E^{0.75}$ will be approximately correct if the stations analysed herein are sufficiently representative to give a fair value for the coefficient c'. Where possible the formula of Prescott should be used since e_d is a better estimate of e_a than is e_m. For consistency within an area the same method of calculation of E_t should be used throughout. This may be done in three ways:

1. If only temperature records are available then this alternative method can be used alone.
2. If humidity records are available for some stations, Prescott's method should be used and the alternative method used for extrapolation by calculating local values for c' as the average of twelve monthly values from the formula
$$c' = 10.\{e_a(1-h)\}^{0.75}/f.(e_a - e_m).$$
3. If evaporimeter records are available within the area both Prescott's method and the alternative method may be used for extrapolation by calculating values for c' or k_1 from the formulae
$$k_1 = E/e_a(1-h)$$
$$c' = E^{0.75}/f(e_a - e_m).$$

This third procedure cannot be regarded as very satisfactory since any particular evaporimeter may be unsuitably sited or maintained. When acceptable calculated values for monthly evaporation, based on sunshine and wind records as well as temperature and humidity, become available, then it is suggested that these values be used as references and Prescott's method or this alternative method be used as means of extrapolation wherever more detailed information is required.

REFERENCES

Bilham, E. G., 1938. The Climate of the British Isles. Macmillan, London.

Foley, J. C., 1945. A study of average hourly values of temperature, relative humidity and saturation deficit in the Australian region from records of capital city bureaux. Commonwealth of Australia, Bureau of Meteorology Bulletin 35.

Gentilli, J., 1953. Die Ermittlung der möglichen Oberflächen- und Pflanzen-verdunstung, dargelegt am Beispiel von Australien. Erdkunde **7**, 81.
Halstead, M. H., 1951. Theoretical derivation of an equation for potential evapotranspiration. Johns Hopkins University, Laboratory of Climatology Interim Report, **16**, 10.
Prescott, J. A., 1938. Indices in agricultural climatology. Journal of the Australian Institute of Agricultural Science, **4**, 33.
Prescott, J. A., 1943. A relationship between evaporation and temperature. Trans. Roy. Soc. S. Aust., **67**, 1.
Prescott, J. A., 1949. A climatic index for the leaching factor in soil formation. Journal of Soil Science, **1**, 9.
Prescott, J. A., Collins, J. A., and Shirpurkar, G. R., 1952. The comparative climatology of Australia and Argentina. Geog. Rev., **42**, 118.
Shepherd, E. M., 1949. Some factors in the hydrology of Queensland. Proc. Roy. Soc. Queensland, **60**, 3.
Thornthwaite, C. W., 1948. An approach toward a rational classification of climate. Geog. Rev., 38, 55.

THE MICROBIOLOGICAL ORIGIN OF THE SULPHUR NODULES OF LAKE EYRE

BY L. G. M. BAAS-BECKING AND I. R. KAPLAN

Summary

The shape of the sulphur nodules of Lake Eyre, especially the flat, plate-shaped ones. suggests that the sulphur might originate from a disintegration. by a series of microbiological and chemical processes, from gypsum crystals. Mass and volume relations between the components are not in conflict with this hypothesis. The sulphur contains organic carbon; moreover. copious plant and animal remains are present, not only on the pellicle often lining the cavity, hut also well within the sulphur core. It may be significant that the sulphur is found at the Ice shore of the Like. A place where both aeolic gypsum and organic flotsam and jetsam accumulate. Direct microscopy showed the presence of a great many microbes in the brine and in the salt crust. as well as on the mud surface. The following groups of: bacteria were isolated: (a) Sulphate reducers, both autotrophic and heterotrophic,

(b) thiobacteria oxidizing sulphur to sulphate; (c) several species of the green Polyblepliarid Flagellate, *Dunaliella,* which constitute, which certain blue-green algae, the photosynthetic component of the biocoenosis. Mass cultures were prepared of microbes which generate hydrogen from glucose-carbonate mixtures (d), methane formation from calcium acetate (e), and denitrifiers (f), and furthermore, of those which promote the aerobic anaerobic decomposition of cellulose and of pectin (g), (h). Only in one case did we obtain evidence of the presence of the photosynthetic bacteria (surface mud). It appeared that the above organisms are, on the whole, halotolerant and in many cases, haliphilic. developing well in 20-25 per cent. brine. Group (a), (b) and (c) are particularly active. From the infection materials, surface mud proved to be the best source, closely followed by the sulphur and the gypsum-crust of the nodule. Examinations of the gypsum crystal showed, in many cases, occlusions of troilite (FeS) or of sulphur. One sulphur mass (containing but little gypsum) was still pseudomorphic after gypsum. Large, clear gypsum (up to *300* grams) when placed in actively growing cultures of *Desulphovibrio (*sulphate reduction) in the presence of iron salts will disintegrate rapidly, 11 per cent. Disintegration being observed in one case in 100 days at 30 deg. C. From these facts, we have derived the following conclusions :

(1) Smaller or larger gypsum crystals are locally subjected to sulphate reduction. for a large part sustained by hydrogen, formed from microbial disintegration of the accumulated organic mass at the lee shore of the lake.

(2) The iron sulphide formed, oxidizes (by an abiological process) when. subsequent to the sulphate reduction, conditions become aerobic.

(3) The sulphur formed by this oxidation will serve as a substrate for then Thiobacteria which, by generating, sulphuric acid, will leach the sulphur mass.

(4) The sulphuric acid, reacting with lime or dolomite, will form the crust of (secondary) gypsum surrounding the sulphur mass. The crustal mass may increase by accretion.

There is reason to assume that the formations are recent, the more so because of a recent sulphur formation described by Subba Rao from coastal regions in India. C_{14} determinations showed an age of 20,000 years. Industrial application of the processes described above should be investigated.

THE MICROBIOLOGICAL ORIGIN OF THE SULPHUR NODULES OF LAKE EYRE

By L. G. M. Baas-Becking* and I. R. Kaplan*

(Communicated by C. W. Bonython)

[Read 14 April 1955]

SUMMARY

The shape of the sulphur nodules of Lake Eyre, especially the flat, plate-shaped ones, suggests that the sulphur might originate from a disintegration, by a series of microbiological and chemical processes, from gypsum crystals. Mass and volume relations between the components are not in conflict with this hypothesis. The sulphur contains organic carbon; moreover, copious plant and animal remains are present, not only on the pellicle often lining the cavity, but also well within the sulphur core. It may be significant that the sulphur is found at the lee shore of the lake, a place where both aeolic gypsum and organic flotsam and jetsam accumulate. Direct microscopy showed the presence of a great many microbes in the brine and in the salt crust, as well as on the mud surface. The following groups of bacteria were isolated: (a) Sulphate reducers, both autotrophic and heterotrophic; (b) thiobacteria, oxidizing sulphur to sulphate; (c) several species of the green Polyblepharid Flagellate, *Dunaliella*, which constitute, with certain blue-green algae, the photosynthetic component of the biocoenosis. Mass cultures were prepared of microbes which generate hydrogen from glucose-carbonate mixtures (d), methane formation from calcium acetate (e), and denitrifiers (f), and furthermore, of those which promote the aerobic and anaerobic decomposition of cellulose and of pectin (g), (h). Only in one case did we obtain evidence of the presence of the photosynthetic purple bacteria (surface mud). It appeared that the above organisms are, on the whole, halotolerant and in many cases, haliphilic, developing well in 20-25 per cent. brine. Groups (a), (b) and (c) are particularly active. From the infection materials, surface mud proved to be the best source, closely followed by the sulphur and the gypsum-crust of the nodule. Examination of the gypsum crystal showed, in many cases, occlusions of troilite (FeS) or of sulphur. One sulphur mass (containing but little gypsum) was still pseudomorphic after gypsum. Large, clear gypsum crystals (up to 300 grams) when placed in actively growing cultures of *Desulphovibrio* (sulphate reduction) in the presence of iron salts will disintegrate rapidly, 11 per cent. disintegration being observed in one case in 100 days at 30 deg. C. From these facts, we have derived the following conclusions:

(1) Smaller or larger gypsum crystals are locally subjected to a sulphate reduction, for a large part sustained by hydrogen, formed from microbial disintegration of the accumulated organic mass at the lee shore of the lake.

(2) The iron sulphide formed, oxidizes (by an abiological process) when, subsequent to the sulphate reduction, conditions become aerobic.

(3) The sulphur formed by this oxidation will serve as a substrate for the Thiobacteria which, by generating sulphuric acid, will leach the sulphur mass.

(4) The sulphuric acid, reacting with lime or dolomite, will form the crust of (secondary) gypsum surrounding the sulphur mass. The crustal mass may increase by accretion

There is reason to assume that the formations are recent, the more so because of a recent sulphur formation described by Subba Rao from coastal regions in India. C_{14} determinations showed an age of 20,000 years.

Industrial application of the processes described above should be investigated.

I. INTRODUCTION

Mr. C. W. Bonython, after visiting Lake Eyre in 1953, had the kindness to send us brine, salt, mud and soil from this region for microbiological examination. He also forwarded a curious "sulphur nodule," a mass of pale yellow

* Division of Fisheries, C.S.I.R.O., Cronulla.

sulphur encased in an ovoid mass of rather coarse gypsum crystals. The discovery of these nodules by Mr. Bonython, and the conclusion drawn by Mr. D. King of the South Australian Mines Department that they are of Sub-Recent formation, may yield valuable clues as to the formation of sedimentary sulphur in general. In 1954 one of us joined Mr. Bonython on a trip to Lake Eyre, where he could collect materials on the spot and also carry out some chemical analysis. The collection of sulphur nodules of various size and formation, together with the clay in which they are formed, brine, salt, surface muds and deep muds, was studied in the laboratory at Cronulla. From this study it appears that the sulphur is of bacterial origin and that the cavities in which it occurs represent a decomposed crystal (or crystal mass) of gypsum. Furthermore, we could find no reason to assume that these nodules could not be formed today, given the proper environmental conditions, as laboratory experiments showed that the process may be initiated in a surprisingly short time.

As Mr. Bonython and Mr. King will publish the geological evidence, it will suffice to add to their observations only such data as are pertinent to our problem.

Sulphur is found at the lee shore, and apparently only at this lee shore, of a very large lake. During flooding much of the organic material would accumulate there. It should also be stated that, although some of the localities were denuded of overlying gypsum, erosion might account for their absence. Smaller and larger crystals of gypsum are present in the immediate neighbourhood of the sulphur sites.

Some of the nodules may be collected from the surface, others may be found to a depth of more than one foot. At the dune side of the deposit, laminated rills of limestone occur. The nodules are mostly of an ovoidal or ellipsoidal shape, reminiscent of ironstone pisoliths (Fig. 1). Figure 2 shows a flat structure, totally unlike a pisolith. The crustal matter consists of gypsum crystals, often with occluded iron oxide. Some lime may be present. Breaking this crust one finds a cavity, partially filled with sulphur. The sulphur contains gypsum crystals of various sizes and is, consequently, of a pale yellow colour. However, in several cases we found a very pure sulphur within the nodule, containing only ·705 per cent. ash. The outside of the sulphur mass may be coated with iron oxide while the inside of the crust shows a lining of organic matter (Fig. 3 near the arrow). Organic remains were also present inside the sulphur (see below). The gypsum crystals on the inside of the crust are partially impregnated with sulphur. In this paper we will try to show that these masses of sulphur are of recent formation, that they can be accounted for by a series of biological and chemical processes and that in the course of events, large crystals of gypsum may be changed into sulphur *in situ*.

II. ANALYSES

The chemical characteristics of the environment are partly known (Madigan, 1930, Bonython and Mason, 1953). The salinity of the brine varies; in 1954 the brine under the salt crust must have been saturated with salt. The solutions are almost neutral, from pH 7·20 at a depth of 12-13 inches, to 6·72 under the surface and 7·00 at the surface. At 11 ft. depth the brine had a pH of 7·12. The total base of the water, consisting of bicarbonate, was $1{\cdot}85.10^{-3}$ in the brine from 11 ft. depth, increasing to $2{\cdot}85\text{-}3{\cdot}05.10^{-3}$n. near the surface. These values are close to those observed in seawater (average $2{\cdot}45.10^{-3}$n.). The electrode potentials, especially in the regions where sulphate reduction occurred, were fairly high (− ·110 to + ·060 volts). Field observations showed both lower pH and electrode potential values as the measurements on the same materials later in the laboratory.

TABLE 1.

Lake Eyre—Analyses of Brine, Mud and Sulphur.

All data in p.p. 10^6 if not otherwise indicated	Brine, surface	Brine, 0-12"	Brine, 12-13"	Brine, 9¾ ft.	Brown surface salt	Pink salt	Mud, surface	Mud, under 11" of salt	Mud, 9¾ ft.	Mud, S-region	Gypsum, S-region	Sulphur, screened	Sulphur, nodule	Artesian bore, 1,600 ft., Frome	Number of analyses	
NaCl	Satd.	Satd.	Satd.	Satd.			89,500	573,900	40,100	35,750		8,000		400	2	See Madigan
Fe					160	70	6,800	1,800	15,000	19,680	5,590	3,120*	30		2, 4*	(1930)
as Fe_2O_3					230	100	9,820	2,580	21,500	28,180	8,010	4,455				Bonython
C							18,500	32,400	13,000	8,850		8,000			1	(1953)
as $C_6H_{10}O_5$							41,500	71,300	29,200	19,900		18,000				
P	70	168					265	100	125	300	128	73		40	2	
as $Ca_3(PO_4)_2$														400		
N, total	82									1,125	675	785			2	
N, NH_3										220		110			1	
HCO_3	173	185		113										1,960	3	
$CaCO_3$	0	0		0								3,200			1	
Sulphur												626,300			2	
Moisture							30,000	29,300		27,000		75,400*	1,100		2, 3*	
Ash												332,700*	7,050		2, 3*	
pH	6·65	6·60	6·70	6·60	6·25	6·90	7·08	7·20	6·40	7·00				8·95	3	
E_h (in mv.)	+340	+360	+450	−350	+420	+425	+370	+10	−110	−280					2	

	Field Observation		Ten days later	
	pH	E_h	pH	E_h
Surface brine	6·65	+340 mV	7·09	+475 mV
0-12"	6·60	+360 mV	6·72	+500 mV
12-13"	6·70	+450 mV	7·20	+470 mV
11' 4"	6·60	+350 mV	7·12	+440 mV

The titration curves of the brine showed a flattening near pH 5·8. We do not know of any acid with a pK of 5·8, but it should be mentioned that the same "plateau" has been observed to occur in seawater in which algae had been growing.

Mud taken from under the salt crust was vacuum dried and submitted to mechanical analysis. It showed the following size-distribution of particles:

Larger than 800 μ	16·3 per cent.
600-400 μ	24·0 per cent.
400-200 μ	16·9 per cent.
200-100 μ	12·5 per cent.
Smaller than 100 μ	32·3 per cent.
	100·0 per cent.

All the fractions isolated seemed to consist almost entirely of gypsum crystals, often with brownish to black inclusions. Highly magnetic particles were isolated from this mud; they were found by X-ray analysis to consist almost entirely of ilmenite. We are indebted to the Australian Microanalytical Service, C.S.I.R.O., Head Dr. K. W. Zimmermann; Mr. J. Waugh, the Ministry of Supply, Defence Research Laboratories, Sydney, and to the Hydrological Section of the Division of Fisheries, C.S.I.R.O., Head Mr. D. Rochford, for further analytical data on the various materials collected (see Table 1).

The analysis of the brine in the following table was derived from an average of three samples collected by Madigan (1930).

TABLE 2.

Cl^-	171,000	p.p.m.
Br	64	p.p.m.
HCO_3^-	154	p.p.m.
$SO_4^=$	12,000	p.p.m.
PO_4^-	365	p.p.m.
Na^+	107,000	p.p.m.
K^+	830	p.p.m.
NH_4^+	18	p.p.m.
Ca^{++}	950	p.p.m.
Mg^{++}	4,030	p.p.m.
SiO_2	47	p.p.m.
Organic matter about	3,000*	p.p.m.
Solids	300,000†	p.p.m.

* Inclusive of 68 p.p.m. N.

† Approximate.

Although not mentioned in the Analysis, boron should be present, as it was found in this laboratory that *Dunaliella*, the chief photosynthetic organism in the brine, requires at least 5 γ/L boron for its development (unpubl.).

Apart from the very low magnesium content, the Lake Eyre brine is not unlike that of Great Salt Lake, Utah. As many microorganisms are influenced by ionic antagonisms, the proportions between the main ions may be of importance.

The muds show a high gypsum content (the salt "slush" under the crust excepted), a high organic content under the salt crust, while considerable iron occurred both in the deep mud (9½ feet) and in the mud of the sulphur region (see Table 3).

TABLE 3.

	Mud Surface	Mud under 11" salt	Mud 9½'	Mud S region	Sulphur	Gypsum
gypsum*	59·65	5·82	65·79	64·14	34·80	
NaCl	3·95	57·39	4·01	3·75	·80	
Fe_2O_3	·98	·26	2·15	2·82	·45	·08
Ca phosphate	·27	·10	·13	·30	·07	·13
C as $C_6H_{10}O_5$	4·15	7·13	2·92	1·99	1·80	
Total N**				·11	1·08	·07
moisture	30·00	29·30	25·00	27·00	7·54	
lime					·32	
sulphur					62·63	

* Inclusive of lime, sulphur-sample excepted.

** NH_4 about 16% of total N.

The NaCl in the mud was present in a saturated solution. The moisture, as determined was partly water of crystallisation of the gypsum $CaSO_4.2H_2O$ and partly brine.

The "crude sulphur" contained approximately 34·8 per cent. gypsum, the moisture content (7·54 per cent.) being nearly all water of crystallization (7·21 per cent.). This sulphur is much lower in gypsum, iron, salt and phosphate than the clay in which it occurs. Only the organic carbon content proved to be similar in the two materials. Most of these substances occur in the outer pellicle, lining the cavity of the sulphur nodule.

The presence of organic remains within the nodule suggested its biological formation. In order to account for the large masses of sulphur within a nodule, the only logical material would be the large crystals of the desert gypsum itself.

If the sulphur actually originated from a large gypsum crystal, there might be some relations of mass and volume indicative of such a process. As said before, the shape of the nodules is sometimes flat, and this would match the often plate-shaped fragments of the desert gypsum. Often the cavity shows roughly the outlines of the crystal (angles of approximately 60 deg.). The masses of sulphur weighed by us varied from 9·8 to 87·0 grams. Two nodules, already open, were carefully emptied, the sulphur weighed and the volume of the cavity determined by filling it with water. Nodule 1 had only a small opening, and the volume of the cavity may be close to the true one. In Nodule 2, the volume as determined was certainly smaller than the original. It must be remarked that the sulphur from the cavity has a specific gravity close to 1·00

(value for sulphur about 1·96) showing that it contains much air. If this sulphur were derived from gypsum 32 grammes of sulphur would correspond to 172·14 grammes of gypsum. As the density of gypsum is 2·34, 32 gr. S would occupy a space of 73·6 cc. We found:

	Nodule 1	Nodule 2
Volume in c.c.	14·0	more than 81·0
"sulphur" in grams	9·75	64·10
63% of "sulphur" (S)	6·15 g.	40·04
Calculated:		
corresponding gypsum	33·2 g.	217·0
volume of this gypsum (in c.c.)	14·2	92·8

This coincidence can hardly be accidental. There is reason to believe that the sulphur, therefore, represents the remnant of a decomposed gypsum crystal.

In both cases the sulphur occupied about 70 per cent. of the volume (69-73 per cent.). This is also what we would expect if the sulphur were formed from a single crystal or from a crystal mass of gypsum. The weight of the crust bears no relation to the weight of the sulphur.

The crude sulphur, boiled in distilled water, did not yield any analyzable substance. The pH did not change, no titratable matter went in solution. Reactions on sulphite and thiosulphate were both negative. In one instance, however, when boiling a greyish mass of sulphur from the centre of a large nodule, the water showed a pH of 5·4.

III. BIOLOGICAL

One of us obtained in 1929 samples of Lake Eyre brines from the late Dr. C. T. Madigan. The brines were later cultured and examined in the Leyden laboratory by Miss T. Hof (1935) and by Miss J. Ruinen (1938). A great number of microorganisms, algal, protozoal and bacterial, were found. In this paper we will draw up a list of organisms, observed by us from the samples collected by C. W. Bonython in 1953 and by I. R. Kaplan in 1954. Direct microscopic examination of brines, salt crusts and mud surface showed the following:

In the first place the common green and orange salt flagellates *Dunaliella*, chiefly the large form, *D. salina* Teod var. *oblonga* Lerche. This form showed a mass development in 1953 when it attributed an orange colour and a violet-scent to the brine. Water-dispersed carotinoids were present.

D. minuta, Lerche 1953 present; 1954 present
parva, Lerche 1953 present, 1954 present
euchorld, Lerche 1953 present, 1954 present

an unnamed species, 15 μ long, spindle shaped 1953 absent, 1954 present. A filamentous blue-green alga, a common soil cover in the desert and observed in the Broken Hill region (L.B.B. 1951, Silverton):

Nodularia spumigena Mertens var. *maior* Kütz (Born & Flah).

Of the diatoms, *Pleurosigma* sp. was common in the more diluted brine in 1953, while the common salt diatom, *Amphora coffaeiformis*, could be observed in both years. Colourless ciliates and flagellates are plentiful, especially Bodonids. A filamentous *Lyngbya* (blue-green) appeared in various materials, nearly always accompanied by a fungus (Chytrid). Direct microscopy yielded, furthermore, large *Spirilla*, long rod-shaped bacteria and the curious *Bacterium*

halobium Petter which is the cause of the "candy-pink" colour of some brines and salts. *Parartemia*, a brine shrimp, occurred in one locality in 1953.

The papery pellicle, lining the cavity of the sulphur nodule, proved to consist almost entirely of organic matter. Microscopy showed the presence of:

(a) Cysts (of *Dunaliella salina* Teod?).
(b) Ideoblast of a proteaceous plant (*Hakea*?).
(c) Tracheids (probably coniferous, *Callitris*?).
(d) Bundles of slender filaments, probably shrunken blue-green algae.
(e) Pollen grains (?).
(f) A tough, light-brown mass, maybe a bacterial film. Leaf-like material, together with *Dunaliella* cysts, was found inside a mass of sulphur. Long, slender prosenchyma cells were seen.
(g) Scales and setae of a moth.
(h) Shell-fragments.
(i) On one occasion an inch-long fragment of a ribbon-shaped monocotyledonous leaf was found imbedded well within the sulphur mass.

These findings point to the formation of the sulphur mass on a leeshore, where microscopic and other flotsam and jetsam accumulate. The S-E shore of Lake Eyre North would be such a locality. Moreover, the material cannot be *very* old!

Most of the biological evidence was obtained from enrichment cultures and, in some cases, pure cultures of various bacterial groups. As most of the results will be published elsewhere, a brief statement will suffice. The following groups were studied in various media and from various infection materials:

(a) Sulphate-reducing bacteria, which change sulphate into sulphide. Two types were studied; those that derive their energy directly from hydrogen and those that derive their energy from organic hydrogen (autotrophic and heterotrophic strains).
(b) Sulphur-oxidizing bacteria. With thiosulphate or sulphur as a source of energy, these bacteria assimilate carbon dioxide with the formation of sulphite and of sulphate.
(c) Photosynthetic (coloured) sulphur bacteria, oxidizing H_2S to S and, in the case of the purple bacteria, oxidizing this sulphur to sulphate.
(d) Green flagellates, such as *Dunaliella*.
(e) Aerobic and anaerobic decomposition of cellulose.
(f) Anaerobic gas formation (hydrogen) from glucose-calcium carbonate.
(g) Anaerobic gas formation (methane) from Ca-acetate.
(h) Anaerobic denitrification.
(i) Pink bacteria of the *B. halobium* group (aerobic, glucose-yeast, or fish-agar).

In short, the cycle (or metabiosis) will run as follows: The *green flagellates* (1) will assimilate CO_2 in the light, even in saturated brines. They will accumulate organic material which will decompose. There will be additional aeolic flotsam, also driven to the leeshore. We will consider here only the anaerobic decomposition and only briefly mention the aerobic *pink bacteria* (2) (*B. halobium* Petter, see Hof, 1935) because of the candy-pink coloration of both brine and salt caused by these organisms. They are important in fish-spoilage, but do not concern us here. It stands to reason that all organisms mentioned are able to perform in highly concentrated solutions.

The carbohydrate (cellulose) material partly prepared by the orange and green *Dunaliella* will be changed by *cellulose fermentation* (3) or *pectin-fermentation* (3a) with the production of organic acid and hydrogen. These

materials will serve to enable *Desulphovibrio* to *reduce the sulphate* (4) to the sulphide and when iron is present, black FeS (troilite) is formed. Certain sulphate-reducers may live on an inorganic medium if hydrogen is present. *Dunaliella* is a nitrate organism and it would be important to see whether *denitrification* (5) could be active with the formation of nitrogen from nitrate. Furthermore, the formation of marsh gas (6) by methane-forming bacteria might be initiated under anaerobic conditions.

If the FeS or H_2S has been oxidized to sulphur (see below), the *Thiobacteria* (7) may oxidize this sulphur to sulphuric acid. The acid formed will have a highly solvent action on mineral matter, it will efficiently leach the sulphur until it does not contain enough necessary nutrient for the *Thiobacteria* to continue their development. The following table shows the results obtained.

TABLE 4a.

	Surface brine	Pink salt	Surface mud	Deep mud	Gypsum	Sulphur	Average	Remarks
GROUP I. *Sulphate reduction*								
on Fe (H_2)			2·0	·7	1·0	1·5	1·30	3·0 maximal development dw.
on lactate			3·0	2·7	2·5	3·0	2·80	14 days in 3-5
on pyruvate			3·0	0	0	0	·75	per cent. salt.
on pyruvate +Fe			3·0	0	3·0	3·0	1·50	(30°C.)
GROUP II. *Thiobacteria*								
S. aer			2·0	2·5	2·0	2·5	2·25	3·0 maximal development dw.
S. anaer			1·0	·7	0	2·0	·93	14 days in 3-5
Thio aer			0	2·0	0	2·5	1·13	per cent. salt.
Thio anaer.			0	1·3	1·0	0	·58	(30°C.).
Thioparus			0	2·0	2·0	0	·50	
av.			·60	1·70	1·40			
GROUP III. *Hydrogen formation from*								
Glucose								ml H_2 in 14 days.
NaCl 5%	·70	·25	3·15				1·37	
10	3·15	·05	6·25				3·15	(30°C.).
15	0	4·50	11·25				5·25	
20	5·65	5·65	9·40				6·90	
25	·75	2·90	10·00				4·55	
av.	2·04	2·67	8·01					
GROUP IV. *Denitrification*								
5%	1·25	·02	1·25	ml gas			·83	ml gas.
10	1·88	0	·83				·89	28 days.
15	·25	0	·13				·13	
20	·07	0	·06				·04	
25	·02	0	0				·01	(30°C.).
av.	·49	·01	·06					av. per culture.

TABLE 4a *Continued.*

GROUP V. *Methane formation*								
Acetate 5	0	·16	·25				·02	ml gas 14 days.
10	·25	·16	·25		ml gas × 10		·03	
15	·25	·10	0				·02	
20	0	0	0				0	(30° C.).
25	0	0	0				0	
av.	·01	·02	·01					av. per culture.
GROUP VII. *Cellulose decomposition* (aerobic)								
6·25			+			+		Decomp. in 28 days (30° C.).
9·3			+					
12·5						*		* mud of sulphur region.
18·75			+			++		
GROUP VIII. *Cellulose decomposition* (anaerobic)						av.		
5%	5·60	—	3·80	2·80	3·42	3·91		pH after 29 days at 30° C.
10%	2·87	4·43	2·72	2·66	2·93	3·12		
15%	3·53	3·92	2·80	4·33	2·85	3·48		
20%	4·03	4·55	2·57	2·49	2·70	3·43		
25%	3·62	3·70	2·47	2·44	2·70	2·99		
GROUP IX. *Pink bacteria* (aerobic heterotrophs)								
5%								all negative except surface brine and pink salt in 25% solution.
10%								
15%								
20%								
25%	++	++						

In 1953 we tested the brine, mud and sulphur on the presence of haliphilic sulphate-reducing organisms and Thiobacteria. Development was obtained in media containing up to 20 per cent. salt. As in the higher salt concentrations the incubation time was high (plus one month at 30 deg. C.), we have limited the cultures from the 1954 material to 3·5 per cent. salt. There is evidence to assume that, during the decomposition of the gypsum, the "internal" solution is dilute, due to the formation of reaction-water. The H_2 and CH_4 formation, the decomposition of cellulose and the denitrification were investigated in media containing 5, 10, 15, 20 and 25 per cent. NaCl. A summary will follow:

Group I. *Sulphate Reduction*

(a) On hydrogen (generated from steelwool cleaned with petroleum ether). All infection materials yielded positive results.

(b) On lactate all infection materials positive.

(c) On pyruvate. Only surface mud positive.

On the average the sulphur nodule contains the most varied and the most active sulphate-reducing bacteria.

Group II. *Thiobacteria*

(a) On sulphur, all cultures positive.
(b) On thiosulphate. Surface mud negative.
(c) Thioparus. Gypsum and deep mud positive.

Deep mud and sulphur nodules proved to be the best infection materials.

Group III. *Hydrogen formation* from glucose and calcium carbonate in various salt concentrations. Both brines and surface mud produced much hydrogen, especially at concentrations higher than 10 per cent. salt. A continuous supply of carbohydrate material may generate enough hydrogen to enable the autotrophic sulphate-reducers to perform. Long gram positive rods and also micrococci present.

Group IV. *Denitrification* ("saltpetre-micrococcus") could only be observed by formation of nitrogen from nitrate after a long incubation time in 5 per cent. and 10 per cent. salt from surface brine and from surface mud. The denitrification was negligible in 15 to 25 per cent. salt. As *Dunaliella* is a nitrate organism, it seems comparatively safe at the usual high concentrations of the brine.

Group V. *Methane formation* was virtually absent. Below 10 per cent. salt, traces of gas were formed.

Group VI. *Dunaliella.* From brown surface salt we raised, in 20 per cent. NaCl (nitrate, phosphate), two forms *D. minuta* Lerche and *D. parva* Lerche. Microscopic examination of brine and salt convinced us, however, that many more species are present in the natural environment.

Group VII. Aerobic decomposition of cellulose. Filterpaper discs were partly disintegrated in 6-19 per cent. salt after 28 days incubation at 30 deg. C. The sulphur nodule and surface muds yielded positive results (long, slender rods and *Spirilla*).

Group VIII. The anaerobic cellulose fermentation yielded highly acid solutions. Neutralization by means of $CaCO_3$ was not followed by sulphate reduction. Only after steelwool was introduced, sulphate reduction appeared in various concentrations, showing that free hydrogen (as developed in the glucose-$CaCO_3$ media) seems necessary.

The surface mud seemed to be the richest source.

TABLE 4b.

Salt-conc.	Surface brine	Surface mud	Deep mud	Mud from Sulphur region	Total
5%	1·5	0	1	0	2·5
10	·5	3	1	3	7·5
15	·5	1	0	0	1·5
20	·5	3	2	0	5·5
25	·5	1	·5	0	2·0
Total	3·5	8·0	4·5	3	

The maximum development in any particular culture is taken as 3.

Summarizing, we may say that not only the liquid and solid environment of the sulphur nodule, but the sulphur itself as well, are teeming with microscopic life, able to promote the cyclic changes necessary for the formation of the sulphur from gypsum and its subsequent purification.

The absence of purple and green bacteria seems remarkable. They could not be isolated either from the 1953 or from the 1954 materials, except in one isolated case from surface mud grown in a medium containing 20 per cent. NaCl.

IV. DISCUSSION

Gypsum crystallizes in the monoclinic system, angle of the axes 58°10′. Figure 4 shows a fragment of a very large crystal of desert gypsum ("old man's bones") which must have weighed nearly one kilogram, collected near Broken Hill, N.S.W. The main cleavage planes are well recognizable. Gypsum may be split along these planes in very thin, glass-like slices. These slices may stand considerable bending. After release of the stress, the surface becomes plane again. The calcium atoms are joined by sulphate groups (Bragg, 1937; Wyckoff, 1931). Two layers of these $CaSO_4$ molecules alternate with two layers of water molecules, joined to the calcium and the oxygen atoms. It is well known that the thermal expansion of the gypsum crystal is many times greater perpendicular to the main cleavage plane than in the direction of this plane. The ease of the splicing of the crystal may be readily explained, only one water molecule being necessary in the lattice to satisfy the bonds. Gypsum is soluble in acids, but also in organic substances containing OH groups, such as glycerol. This dissolution again will be carried out on the water surfaces in the molecule until a double layer of $CaSO_4 2H_2O$ remains. The crystal takes up dyes and inorganic chemicals very slowly. By heating and cooling the process may be speeded up, due to the thermal expansion and contraction. One may impregnate a small (5 mm.) crystal with ferric chloride in this way, and react on the iron with K-ferrocyanide. Inclusions have frequently been reported in gypsum. They must be of two kinds; either the crystal will be formed around some impurity, or there will be a later penetration of materials, helped by heating and cooling. As Figures 7 and 8 show, these inclusions are of a variable nature; organic matter, sulphur, FeS and iron oxide have been demonstrated to occur within the crystal. (See also Silvestri, 1882; Sjögren, 1893.)

The above facts may be accounted for by a simple working hypothesis:

(a) Single gypsum crystals, or concretions of such crystals, are brought in contact, when submersed, with a substrate, fit for the development of halophilic sulphate reducing bacteria. This will require a preliminary fermentation of the organic material, with the generation of either hydrogen (on which the autotrophic strain of sulphate reducers will thrive) or organic acids (a fit substrate for the heterotrophic strain). The gypsum may or may not contain iron oxide the environment will invariably contain iron, as appears from the analytical data. Let us suppose further that sufficient ammonium ion, phosphate and carbon dioxide be present for sulphate reduction to set in. During this reduction the S-O bonds are disrupted and the crystal will disintegrate in the main plane into fibrous crystallites (see Fig. 9).

The following reaction will take place:

$$CaSO_4 2H_2O + 8H \rightarrow CaS + 6H_2O$$

The molecular volume will change considerably chiefly due to water of reaction. There will be a considerable expansion, which will assist in the breakdown of the crystal. Sjögren (1893) mentions a 4·023 per cent. salt solution from the inside of a 30 cm. long gypsum crystal from Girgenti (Sicily). The gas phase consisted chiefly of H_2S. From the ionic balance (on recalculating the analytical figures) it appears that the solution must have been about 0·14n. in sulphide. No iron was present. FeS will always be formed, if the pH is higher than 5·8. (Due to the very low solubility product of FeS, H_2S will even remove the iron from phosphates.) We get:

$$CaS + Fe(OH)_2 \rightarrow Ca(OH)_2 + FeS$$
$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O.$$

The overall equation will be:

$$CaSO_4 2H_2O + 8H + CO_2 + Fe(OH)_2 \rightarrow FeS + CaCO_3 + 7H_2O$$

again with an increase in molecular volumes. Figures 5, 7 and 8 show the FeS inside the crystal. This reaction, which proceeds to 92 per cent. completion (according to the analyses) gives rise to either CaS or FeS, or both, compounds that will oxidize readily.

(b) Verhoop (1940) has shown that the oxidation of FeS is a purely chemical process, taking place in a short time at 100 deg. C. At room temperature it may take 8-12 hours,

$$4FeS + 3O_2 \rightarrow 2Fe_2O_3 + 4S.$$

Here again there is an increase in molecular volume. Figures 5 and 6 show the sulphur inside the crystal. At times the shape of the gypsum crystal is still recognizable, while it consists, for the largest part, of sulphur (Fig. 5).

It will be seen that, while the sulphate reduction will also generate water, both sulphate reduction and sulphide oxidation will cause expansion, assisting in this way in the disintegration of the crystal. The "fluffiness" of the sulphur (its low density) also bears witness of this expansion. Moreover, the acid products of the thiobacteria will wash much gypsum from the nodule, which gypsum may recrystallize at the outside. Part of the outside shell of the nodules may be formed by action of HSO_4^- with the lime in the clay. The outer part of the shell may have formed by accretion as well.

This disintegration will proceed rapidly. We isolated a sulphate reducer from Lake Eyre, on a 5 per cent. NaCl-lactate medium. A gypsum crystal, without any visible inclusions, was placed in a medium containing, besides ferrous ammonium sulphate, phosphate and bicarbonate, a 1 per cent. solution of sodium acetate. After a few days at 30 deg. C. the crystal became covered with black flakes of FeS (Fig. 10). These flakes consisted of small, columnar crystallites, under an angle of 26 deg. with the a-axis of the crystal (see Fig. 9). Similarly, the occurrence of FeS within the crystal occurs between these planes. In 10 days 4·5 grams of the large crystal (weight 631 grams-) had been decomposed or was disintegrated; over 11 per cent. was consumed in 110 days. At this rate the crystal would be decomposed in a little less than three years. Steady and optimal conditions should persist, however, during this period, a steady stream of nutrients (such as may be found near the lee shore) being the prime prerequisite.

(c) When the sulphur still contains nutrients, such as ammonium salts and phosphate, there will be an inevitable action of the *Thiooxidans* group of bacteria, generating acid. Even a little acid will leach the sulphur completely, the extraneous elements and part of the gypsum being washed out. We believe that the core of the sulphur nodules contains but very little inorganic salts. As soon as the substances necessary for the sulphur oxidation are removed they will accumulate in the outer crust. Gypsum easily recrystallizes from a saturated solution.

Again we want to emphasize that all of the bacteria necessary for the above reactions are still present, apparently in great numbers, within the sulphur nodule. While "everything is everywhere" at least as far as soil and water bacteria are concerned, bacteria cannot wait forever. Porous coal, from an open seam at Coal Cliff Mine, N.S.W., was flamed at the outside. Sulphate reducers, either autotrophic or heterotrophic, could *not* be isolated from this material. However, it yielded cultures of *Thiobacteria*, which are known to be active in mines (acid minewaters). The curious "empty" nodules, collected at the northern portion of the W-coast of Scalloped Bay by Mr. Bonython, yielded neither sulphate-reducing nor sulphur-oxidising bacteria.

In a preliminary C_{14} age determination carried out by Mr. T. A. Rafter and Mr. G. Ferguson, Dominion Physical Laboratory, D.S.I.R., Wellington, New Zealand, on a composite sulphur sample weighing 2·2 Kg. from west coast of Sulphur Peninsula, 3·7 litres of CO_2 were obtained. This was sufficient for an age determination, the result being 19,100 ± 500 years. This result could mean that old carbon was contaminated with 9·2 per cent. of living carbon. Further isotope measurements are being carried out and the results will be quoted in a separate publication.

If we assume that this datum is correct (it appears to confirm Mr. D. King's stratigraphic finding), then the first step (sulphate reduction) could have taken place at a period of 20,000 years or longer, while the second step of sulphur oxidation occurred much later under drier conditions, and is probably still taking place in this older material. Many of the sulphur nodules contain bits of insects, leaves, and matter probably washed in prior to the formation of the gypsum shell.

It seems very remarkable that all of the bacteria isolated were either highly salt-tolerant or halophilic, while the sulphur only contains 0·8 per cent. salt. This may be accounted for by the fact that most of the sulphate reduction inside the crystal will be performed by materials already occluded by the growing gypsum crystals or be removed by the leaching under the acid conditions created by the *Thiooxidans* bacteria.

The first author visited the gypsum-salt lakes in South Australia in 1936. There he met conditions so similar to those observed at Lake Eyre* that further examination of the gypsum cliffs of the Yorke Peninsula Salt Lakes (Marion Bay, Lake Fowler) might yield other localities where native sulphur is formed.

After completion of this paper we found that Subba Rao (1947) had observed sulphur formation in coastal clays in India. His brief account matches ours in many aspects.

We know that many believe that the sedimentary sulphur deposits (e.g. from Texas) are of biological origin (Thode *et al.*, 1953 and 1954). We share this belief. The application of Lyell's "actuality principle" seems equally valid in geobiology as it is in geology. It may be that at some time gypsum will be used to prepare sulphur by bacteriological means.

REFERENCES

Baas-Becking, L. G. M., 1934. Geobiologie. The Hague, van Stockum.

Bragg, N. L., 1937. Atomic Structure of Minerals. Cornell Univ. Press.

Bonython, C. W., and Mason, B., 1953. The filling and drying of Lake Eyre. The Geographical Journal 119: 321.

Hof, T., 1935. Investigations Concerning Bacterial Growth in Strong Brines. Rec. des Trav. Bot. Neerl. 32: 92.

Jack, R. L., 1921. The Salt and Gypsum Resources of South Australia. Geol. Survey S.A. Bull. No. 8, p. 26.

Madigan, C. T., 1930. Lake Eyre, South Australia. The Geographical Journal 76: 215.

Ruinen, J., 1938. Notizen ueber Salzflagellaten II. Arch. f. Protistenk. 90: 209.

Ruinen, J., 1938. Notizen ueber Ciliaten aus konzentrierten Salzgewassern. Zool. Mededelingen Mus. Nat. Hist. Leyden 20: 243.

Ruinen, J., and Baas-Becking, L. G. M., 1938. On Rhizopods Living in Unusual Environment. Arch. Neerl. de Zoologie 3 (supplement): 183.

Silvestri, O., 1882. Sulla natura chimica di alcune inclusioni liquide contenute in cristalli naturali di solfo della Sicilia. Gaz. chim. Ital. 12: 7.

Sjögren, Hj., 1893. On Large Fluid Enclosures in Gypsum from Sicily. Bull. Geol. Inst. Uppsala 1-2: 281.

Subba Rao, M. S., Iya, K. K., and Sreenivasaya, M., 1947. Microbiological Formation of Elemental Sulphur in Coastal Areas. Fourth Int. Congr. Microbiol., p. 494.

Thode, H. G., Macnamara, J., and Fleming, W. H., 1953. Sulphur Isotope Fractionation in Nature and Geological and Biological Time Scales. Geochim. et Cosmochim Acta 3: 235.

* For a very good description see Jack, 1921.

THODE, H. G., WANLESS, R. K., and WALLOUGH, R., 1954. The Origin of Native Sulphur Deposits from Isotope Fractionation Studies. Geochim. et Cosmochim. Acta 5: 286.
VERHOOP, J. A. D., 1940. Chemische on Microbiologische omzetting van Yzersulfiden in den Bodem. Thesis, Leyden, H. Veenman & Co., Wageningen.
WELLS, A. F., 1947. Structural Inorganic Chemistry. Oxford, Clarendon Press.
WYCKOFF, R. W. G., 1931. The Structure of Crystals. Am. Chem. Soc. Mon. 2nd Ed. Chemical Catalogue Co., N.Y.

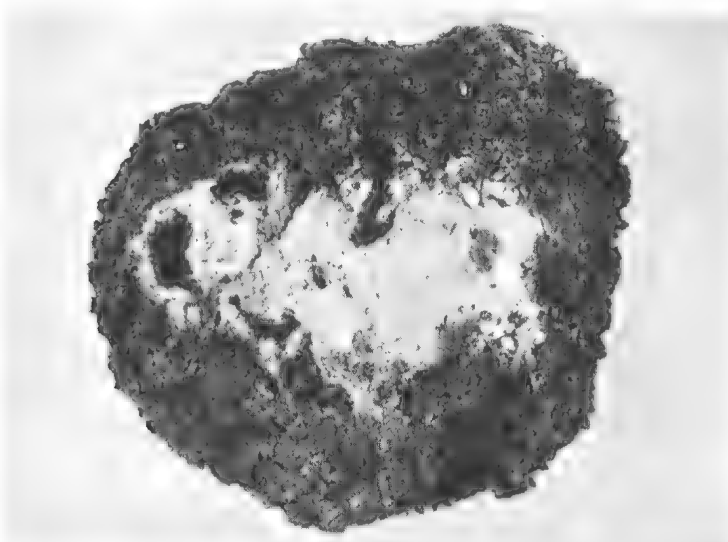


Fig. 1.—Sulphur nodule, opened, showing sulphur and cavities.

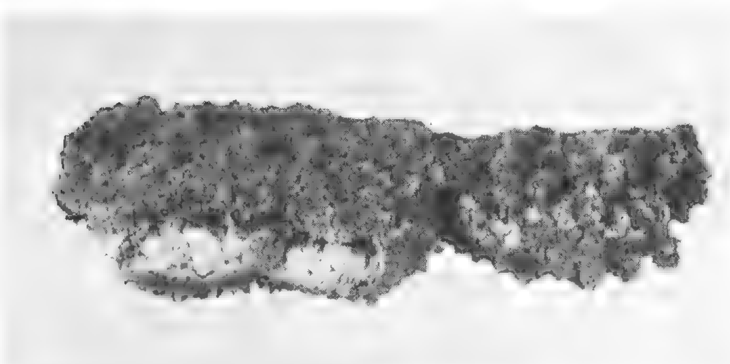


Fig. 2.—Sulphur "nodule", plate-shaped. The internal cavity has the shape of a plate-crystal of gypsum.

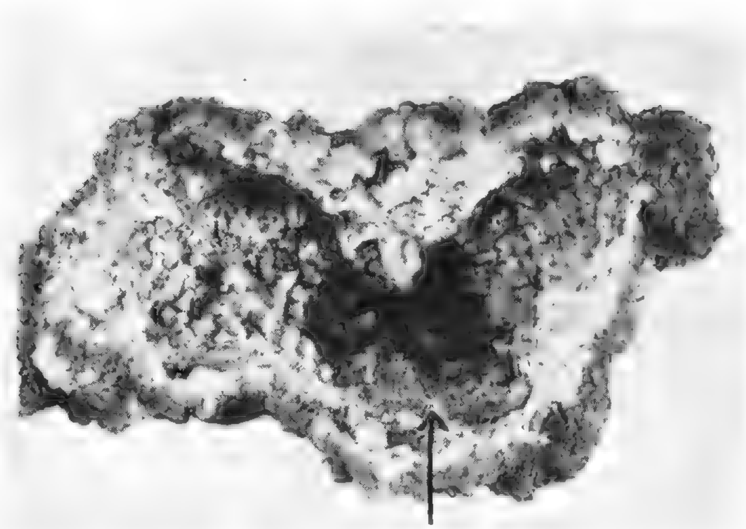


Fig. 3.—Nodule, from which the sulphur is removed. Some of the lining gypsum crystals are partly "sulphurized".

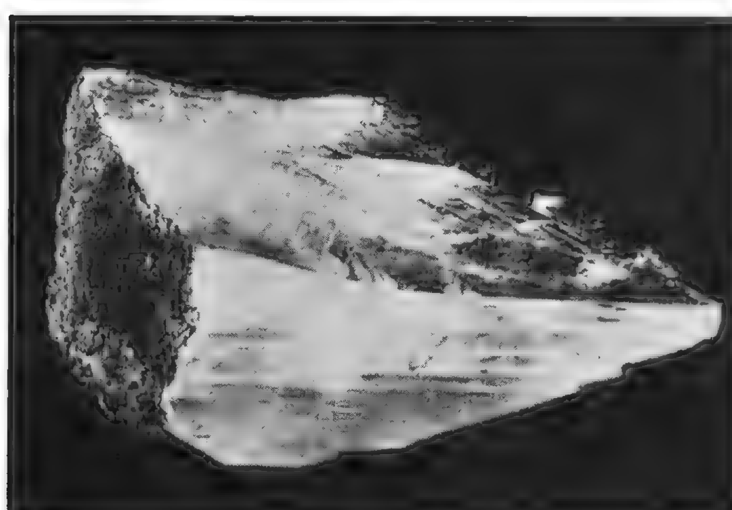


Fig. 4.—Fragment of gypsum crystal, collected near Broken Hill, N.S.W. Courtesy of Mr. R. Stanton.

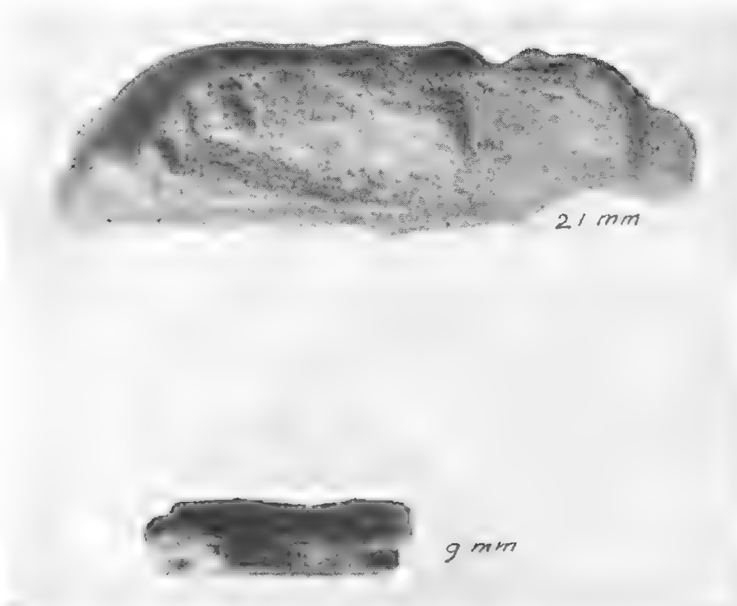


Fig. 5.—Pseudomorph of gypsum, consisting almost entirely of sulphur. Where it has been scratched with Gillette blade, small pits mark crystal debris left. Gypsum crystal with occlusions of FeS.

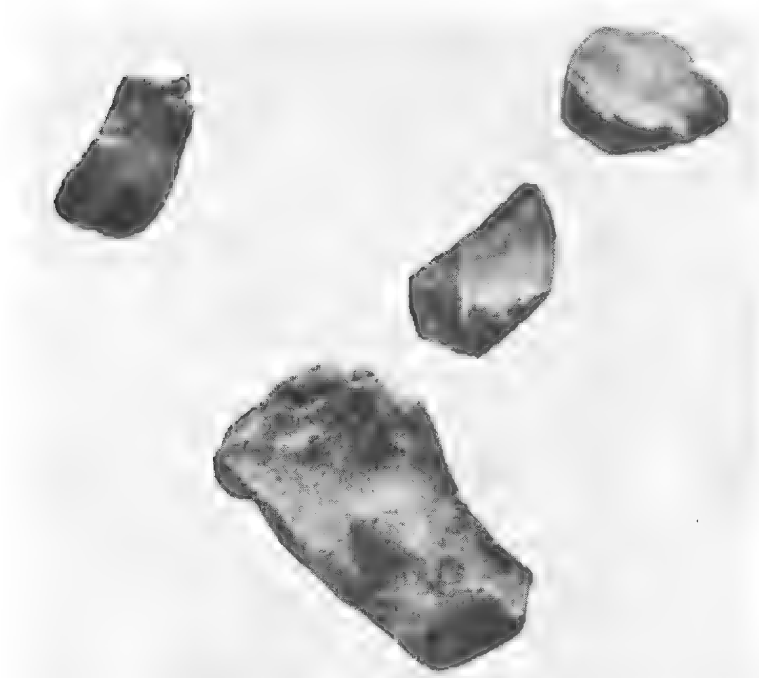


Fig. 6.—Sulphur washed away by a jet of water. Remaining, clean gpsum crystals contain much internal sulphur. x 10.

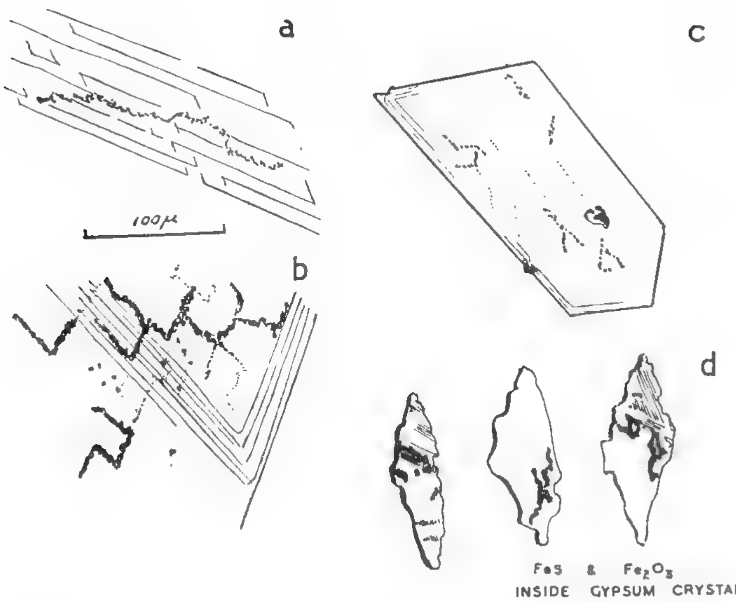


Fig. 7.—(a) Iron oxide particles within the crystal after reaction with K-ferrocyanide. The liquid may be forced in by heating the crystal and on cooling, liquid is sucked in by contraction perpendicular to the main cleavage plane. (b) Troilite (FeS) inside the crystal, following the cleavage planes. (c) Sulphur granules inside the crystal, following cleavage planes. (d) Iron oxide and FeS within a crystal, examined after splitting it with a knife on the main cleavage plane.

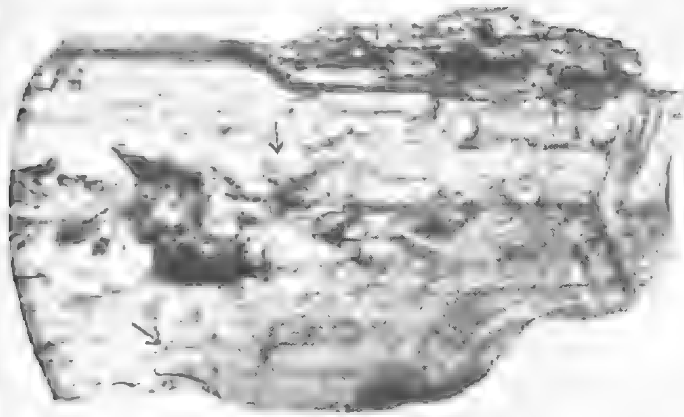


Fig. 8.—Gypsum crystal with occlusions of FeS.

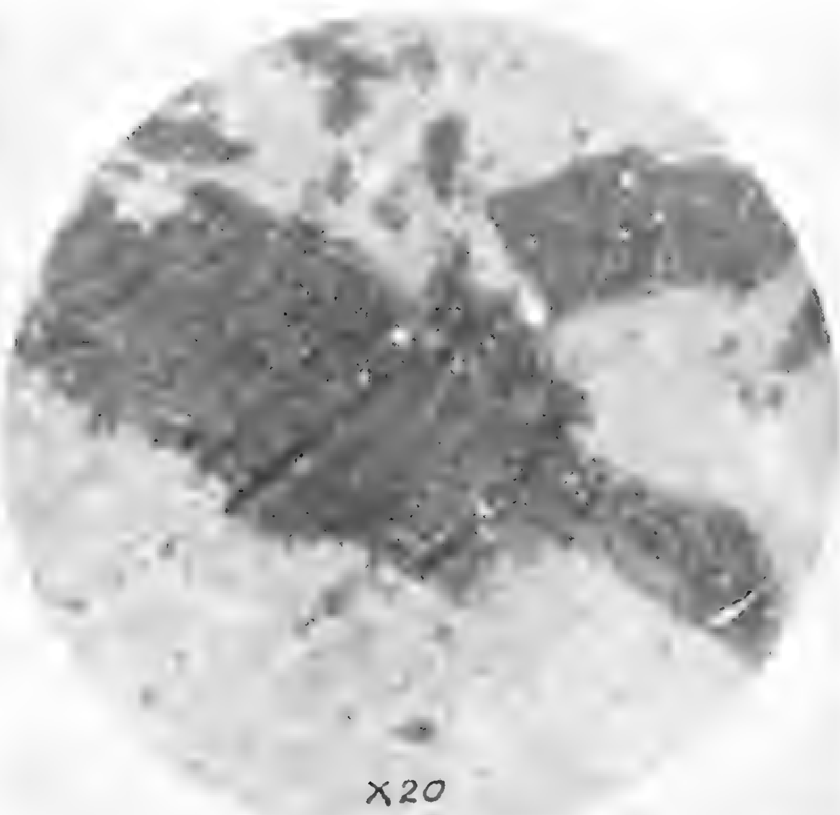


Fig. 9.—Flakes, obtained from crystal. Fig. 10, enlarged. The flakes consist of rod-shaped crystals, still arranged under angles of approx. 74 deg.

Fig. 10.—Plate-shaped crystal, split from the crystal depicted in Fig. 4. The plate-shaped fragment weighed 631 grams. It was infected with sulphate-reducing bacteria from Lake Eyre sulphur, on an acetate medium with Mohr's salt. After 10 days the flaky black crust (containing much FeS) peeled off. Not less than 4·5 grams disintegrated in this period.

THE SALT OF LAKE EYRE - ITS OCCURRENCE IN MADIGAN GULF AND ITS POSSIBLE ORIGIN

BY C. W. BONYTHON

Summary

Journeys onto Madigan Gulf were made by Madiqan in 1929, and by the author in 1953 and 1954. Observations were made of the surface formations, hand bores were sunk and samples obtained, and level surveys were made to determine the physical form of the lake bed.
A tentative map of the lake bed contours has been and from this has been calculated the volume of water that the gulf may hold when filled to different levels. Brine salinities an estimate of the total salt content; an independent estimate is derived from salt crust thickness measurements in the dry lake. The log of a 12-ft. hand bore put down in the lowest part of Madigan Gulf is given.
The different dry salt formations are described and shown in photographs. Their origin is deduced. The succession of events during the drying-up of the lake waters, and during re-flooding of the dry salt crust, is reconstructed. Speculations are made on the origin of the salt. It is shown that the composition of the salt is likely to give little indication of its origin. The total quantity is small compared with the expected intake over short periods of geological time, and the tact that salts are present in quantities in direct proportion to their order of deposition, and in inverse proportion to their solubility, suggests that they exist in a state of equilibrium between an incoming stream and another stream continually being lust.

THE SALT OF LAKE EYRE — ITS OCCURRENCE IN MADIGAN GULF AND ITS POSSIBLE ORIGIN

By C. W. Bonython*

[Read 9 June 1955]

SUMMARY

Journeys onto Madigan Gulf were made by Madigan in 1929, and by the author in 1953 and 1954. Observations were made of the surface formations, hand bores were sunk and samples obtained, and level surveys were made to determine the physical form of the lake bed.

A tentative map of the lake bed contours has been prepared, and from this has been calculated the volume of water that the gulf may hold when filled to different levels. Brine salinities yield an estimate of the total salt content; an independent estimate is derived from salt crust thickness measurements in the dry lake. The log of a 12-ft. hand bore put down in the lowest part of Madigan Gulf is given.

The different dry salt formations are described and shown in photographs. Their origin is deduced. The succession of events during the drying-up of the lake waters, and during re-flooding of the dry salt crust, is reconstructed.

Speculations are made on the origin of the salt. It is shown that the composition of the salt is likely to give little indication of its origin. The total quantity is small compared with the expected intake over short periods of geological time, and the fact that salts are present in quantities in direct proportion to their order of deposition, and in inverse proportion to their solubility, suggests that they exist in a state of equilibrium between an incoming stream and another stream continually being lost.

INTRODUCTION

Recent studies of Lake Eyre promoted by the Royal Geographical Society of Australasia, South Australian Branch, following the phenomenal flooding in 1949-50, included field work which brought to light *inter alia* interesting information on the volume, salinity and geology of the lake and surroundings. Some of the findings have been set out by Bonython and Mason (1953), and later in more detail by Bonython (1955 a, b, c, d and e).

The evaporation study had given rise to rough estimates of the water-holding capacity of the lake at its higher stages, but there still persisted a lack of such data for the lower stages. The known volumes had been estimated from aerial reports on the extent of the flooded areas in conjunction with lake levels measured on gauging posts near the shore, but during the final phase of the drying-up the water retreated inwards from the shore so that its level could no longer be gauged, and hence the residual volumes could not be estimated. The lowest basins of the lake bed — to which the residual volumes relate — are important inasmuch as they appear to contain practically all the lake salts both during the concluding stages of the drying-up process and after the lake is finally dry.

THE EXPLORATION OF THE BED OF MADIGAN GULF

The deepest parts of Lake Eyre North are Madigan Gulf in the south-east and Belt Bay in the south-west; the former is thought to be the deeper of the two.

* I.C.I. Alkali (Australia) Pty. Ltd.

Madigan Gulf is an oblong basin, approximately 25 miles by 20 miles, named after C. T. Madigan, who reached its dry centre in 1929 (Madigan, 1930). After viewing it from the air he had attempted to drive a motor vehicle on it with the object of reaching the centre of Lake Eyre itself—at that time completely dry.

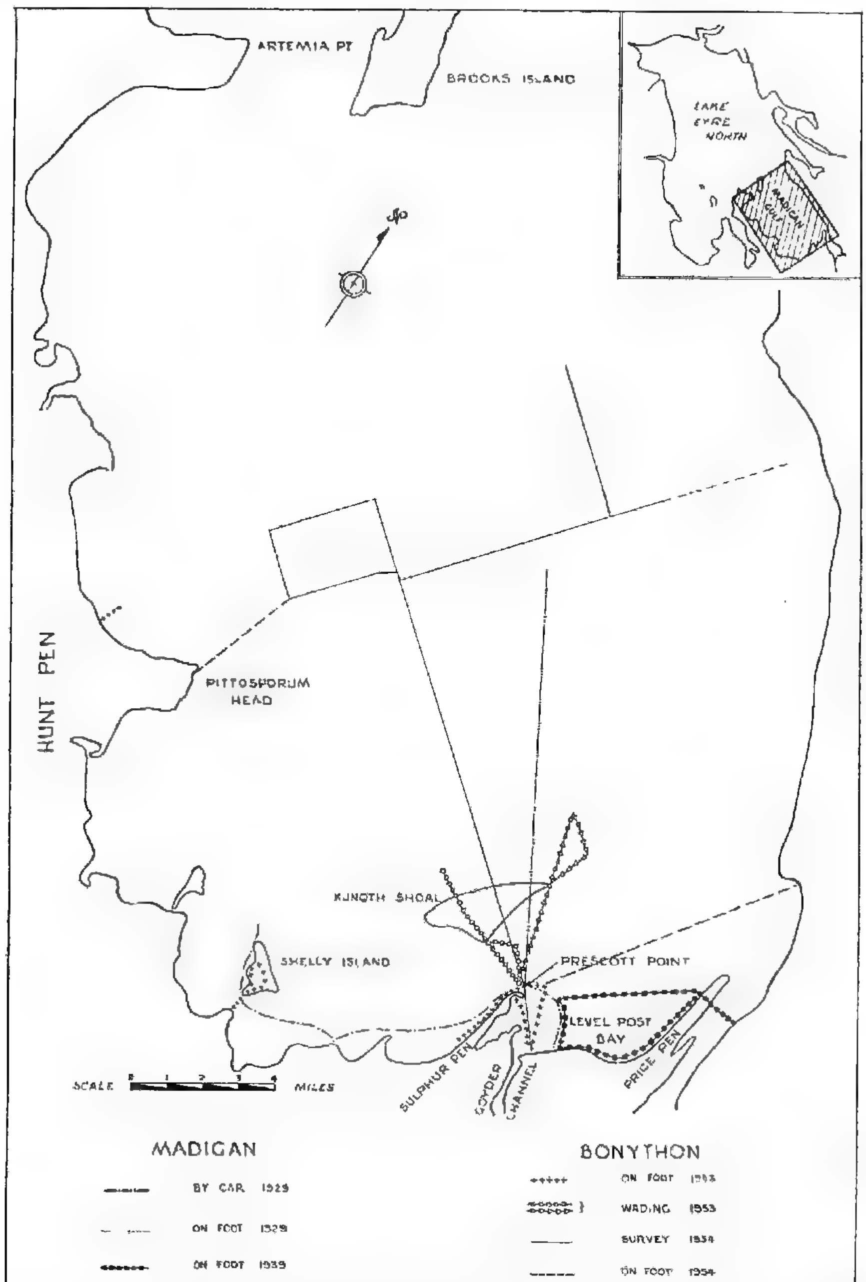


Fig. 1. Journeys on the Bed of Madigan Gulf.

He started from the shore at what is now called Level Post Bay (see Fig. 1), but a marginal strip of the lake bed, composed of damp clay, proved an impassable barrier to his truck, so that he was forced to follow the shore southwestwards until he reached Shelly Island, where his attempt to explore the

gulf by motor vehicle was abandoned. (An interesting postscript to this attempt is that the author in 1953 found ghostly vestiges of Madigan's car tracks west of Sulphur Peninsula; they were still in evidence—see Plate 1a—even after having been submerged for over two years in up to 10 ft. of water.)

During the return journey Madigan and a companion branched off at Prescott Point to walk 11½ miles out into the gulf in a north-westerly direction. He described the various surface salt formations for the first time, and he found the salt crust to increase in thickness with distance from the shore finally to reach 17 inches. He and his party put down some hand bores in the lake bed near the shore. His observations were thorough and complete, and he was clearly a most discerning observer. The amount that he discovered during the mere seven days spent on the lake was truly remarkable. Madigan briefly revisited Level Post Bay in 1939 during the return from his Simpson Desert expedition (Madigan, 1946).

No further scientific work was carried out there until the author made his evaporation expeditions in 1951 (Bonython, 1955 c). When in 1952 the bed of the gulf was being re-exposed as it dried up a plan was formulated to make accurate levelling surveys across it for the purpose of determining its contours; from these the water-holding capacity could be derived. At the same time the salt crust was to be studied in more detail than Madigan had found possible.

The lake had completely dried up by early 1953, so the expedition was planned for May of that year. However, in February and April respectively, two floods entered the lake — the first from the Neales and Macumba catchments, and the second from Queensland via the Diamantina. The latter was a flood of significant proportions (Bonython, 1955 b), such that Madigan Gulf was covered with water to the level of A.B.L. 95·8 ft.* by May, 1953. The expedition of May, 1953, still went out, but with modified objectives. The only survey made consisted of a short levelling traverse across a dry strip of the lake bed near the shore.

Two wading journeys were made from Prescott Point through shallow waters in the Kunoth Shoal area (see Fig. 1); one went for four miles on approximately the magnetic bearing of 285°, crossing the high-and-dry crest of Kunoth Shoal in the process, while the other went for five miles generally on a bearing of 340°, passing entirely through water. A three-day motor journey along Hunt Peninsula was also made during this expedition. Its Madigan Gulf shore was followed round to Artemia Point, the north-eastern extremity.

In 1953, salt and brine samples were taken, hand bores were put down near the shore, and stratigraphic data were obtained by D. King of the South Australian Mines Department (King, 1955). A previously-found deposit of native sulphur (Baas-Becking & Kaplan, 1955, Bonython and King, 1955) was also studied on this occasion.

The lake had dried up again by the end of 1953, and a levelling survey expedition was planned for August, 1954. The lake remained dry, so that this time it was possible to carry out the work as desired. The party of eight members travelled to Lake Eyre in a jeep and a heavy truck, and remained in the vicinity from 23rd August to 3rd September. W. G. Fenner conducted the levelling survey, while the author was responsible for the salt crust boring and sampling. The first phase of the work involved a four-day journey on the lake bed by four men. They used a novel form of transport for their supplies — a light "garden" crawler tractor with widened tracks, drawing a trailer on aeroplane wheels (see Plate 1b). It included a cyclometer wheel to log distances. Though slow (2½ m.p.h.), this vehicle could cross the soft mud near the shore without sinking. It carried such essentials as water, firewood and a tarpaulin shelter which, when fastened to the lee side at night, made a com-

* The scale is defined on page 71.

fortable camp possible in otherwise rather bleak conditions. The surveying pair was able to cover seven miles in a full working day; the other pair drove the tractor, and bored and sampled the salt. Black flags were planted at intervals to mark the survey lines.

The first leg of the survey was advanced from Prescott Point on 25th August in a direction of 305° magnetic (see Fig. 2). (The reason why this bore rather to the left of the long axis of Madigan Gulf was that a certain aerial report of the drying-up in 1952 suggested that the bottom of the basin was on that side: the report was misleading.) The salt crust was encountered a short distance beyond Prescott Point, and it rapidly reached a thickness of 7 in. It later decreased to 1 in. over Knoth Shoal, but after that it thickened once more. The surface was hard, and the only interruptions to its smoothness were small "islands" of cemented crystals of "drift" salt raised a few inches above the general level. Soon the thickness reached 8 in., and over all the distance covered by the levelling team in the next few days it kept between 7 and 11 in.

The second day took the survey to Flag 36/54 at 12 miles. On the third day (27th August) the direction was changed 90 deg. anti-clockwise at the 14-mile mark, and other similar turns were made, so that during this and the fourth day a rectangle of perimeter 10 miles was closed back onto the original survey line. In the course of this, on the morning of 28th August, the author walked from the third camp at Flag 62/54 to the south-western shore at Pittosporum Head and back again. After rejoining the outward survey line at Flag 37/54, the party returned to base. The levels so far measured indicated that the lowest part of Madigan Gulf was probably on the north-east or opposite side of the main survey line. The tractor was very slow, and the 34 miles on the lake so far covered by it had been tedious ones for the drivers. Moreover, the salt crust proved so sound that it encouraged an attempt to put a motor car on to it — the unachieved aim of Madigan 25 years before (Madigan, 1930). By running over planks laid on the soft lake bed where the gap between the land and the salt was narrowest (near Prescott Point), a jeep eventually reached the thick salt crust: thenceforth it was possible to travel at 40 m.p.h. on a smooth surface, most of which was as firm as concrete. After this the survey party was driven out each morning from the advanced base camp at Prescott Point, and brought back in the evening. The jeep track detoured northwards round Knoth Shoal to keep to the thick salt.

On 30th August the next leg of the survey was directed along a bearing of 35° Magnetic from Flag 36/54, 12 miles out. The lake bed was relatively much lower in this direction, the leg terminated after 8 miles at Flag 99/54. Beyond the latter point D. Dyer and the author walked on for three more miles, but were halted at approximately one mile from the north-eastern coast where the salt had tapered to a thickness of one inch, and it was found to be a treacherous area of breakable crust underlain by very soft mud. On 31st August a survey leg on a bearing of 305° Magnetic was begun from Flag 93/54 located part way along the previous day's leg and at its lowest point. At Flag 112/54, four miles along the final leg, the lowest part of the lake bed to be measured was found; the survey ended three-quarters of a mile further on. The lowest point was at A.R.L. 91·5 ft., at 17 miles N.N.W. from Prescott Point.

During 31st August the author and I. R. Kaplan sank a hand bore in the lake bed at Flag 93/54. The bed itself (i.e. the bottom of the salt crust) was at A.R.L. 92·2 ft. here, and so although it was not at the lowest known part of Madigan Gulf it was only 8 in. above it. The bore reached a depth of 11 ft. 4 in. on that day, and it was deepened to 12 ft. 8 in. on the following day with the help of W. G. Fenner. The last 1 ft. 8 in. was in a bed of rotten dolomite. That day — 1st September — saw the end of the effective work of the expedition.

Other information had been gathered by D. Dyer, who in the meantime had taken a party on foot from Prescott Point along a course bearing 30° Magnetic to the north-east coast eight miles away. Salt crust thicknesses up to 4½ in. were measured. On another occasion he traversed Knoth Shoal somewhat to the south of the main survey line.

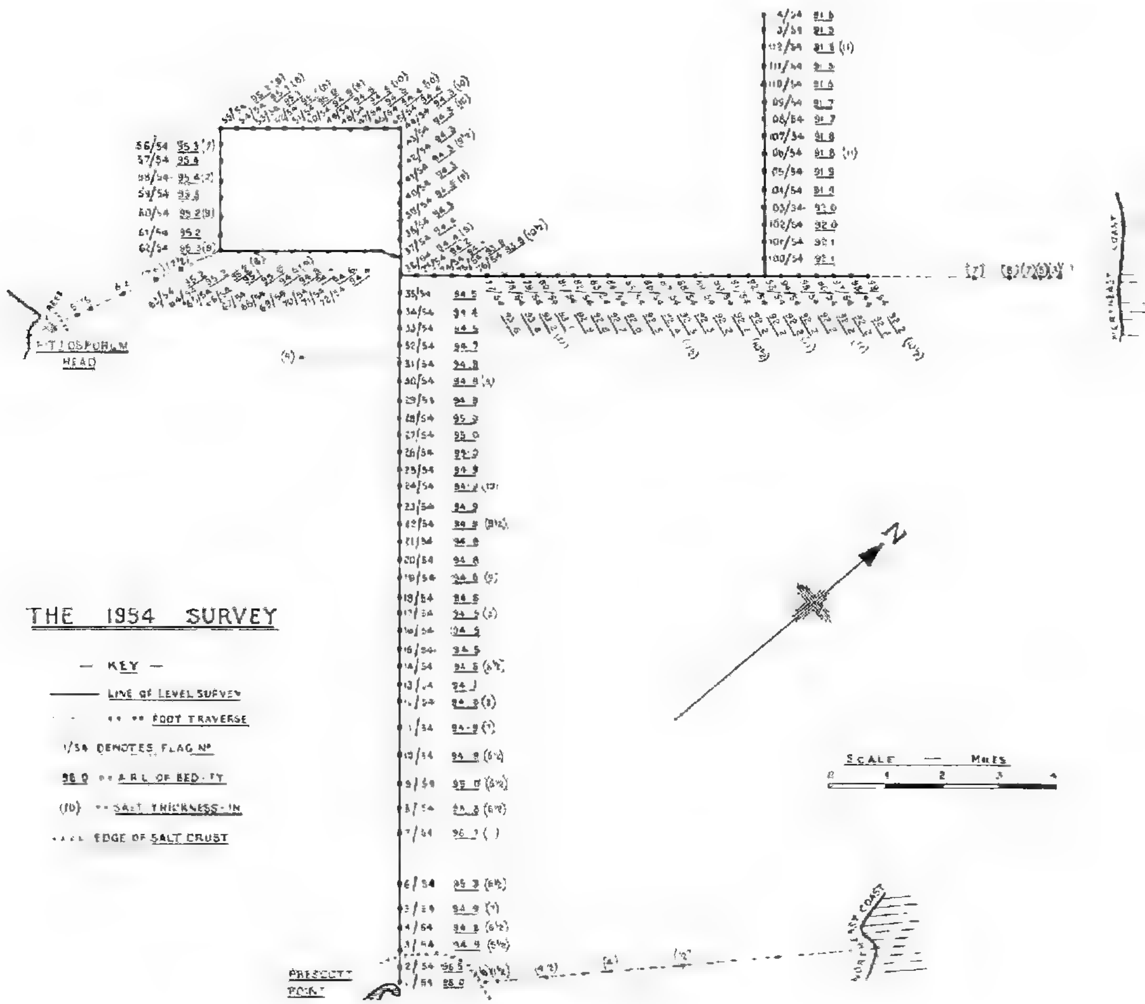


Fig. 2

The survey parties had been eight days on the lake bed, during which a total of 33 miles had been levelled, 55 salt depths had been measured, and 18 shallow salt crust bores and one deeper lake bed bore had been sunk and logged. Many samples of salt, mud, brine, etc. had been taken.

THE 1954 LEVELLING SURVEY

Water levels in Lake Eyre North have been expressed (Bonython, 1955 b) in terms of an arbitrary datum tied to the main level post set up in 1951; the datum is 100 ft. below the zero of the level post, which is at approximately

lake bed level at a point near the shore of Madigan Gulf. The level post zero — Arbitrary Reduced Level 100 ft. — is approximately 25 ft. below sea level (Bonython, 1955 e), and it is roughly midway between the lake's highest stage in 1950 (A.R.L. 107·5 ft.) and the lowest part of Madigan Gulf (A.R.L. 91·5 ft.). Level data below A.R.L. 98 ft. were lacking until 1954, and the work now to be described was done to obtain accurate measurements in this level range. The results refer to the true lake bed (i.e. the bottom of the salt crust), although the actual survey was carried out with respect to the upper surface of the salt.

The instrument employed was a Cooke, Troughton & Simms S300 series Surveyors' Level used in conjunction with an orthodox staff. Determinations were made to the nearest 1/100 ft., but in the following description levels will be reported to the nearest 1/10 ft. Location is specified by the serial number of the flag placed there (and the year — 1954); the lines of the survey are shown in Fig. 2. The level of the lake bed at Flag 1/54, approximately 100 yards north of the sandy hook of Prescott Point, was A.R.L. 98·0 ft. It fell to A.R.L. 94·8 ft. in the trough between the starting point and Kunoth Shoal, rising again to A.R.L. 96·7 ft. at the crest of the latter. Then there was a rapid fall to A.R.L. 95 ft., but in the remaining 11 miles of that leg of the survey the level kept between A.R.L. 95 ft. and A.R.L. 94 ft. It was subsequently realized that this course was approximately parallel to the contours instead of cutting them at right angles as intended.

The levelling of the rectangular "box" south-west of the main survey line showed a rise of less than 1 ft. in that direction. This, and other information, indicates that much of the lake bed between the main survey line and the south-western shore is a nearly flat shelf. Incidentally, the closure of the survey of the "box" revealed a level measurement discrepancy of only ½ in. — a pointer to the accuracy of the survey.

The leg going north-eastwards from Flag 36/54 showed the comparatively steep downward gradient of 6 in. per mile for 3 miles, but by 5 miles (Flag 89/54) the bed had flattened out at A.R.L. 92·2 ft. It scarcely rose at all up to the end of the leg. The final leg north-west of Flag 93/54 showed a slow fall to A.R.L. 91·5 ft. (at Flag 112/54), the lowest point measured, followed by a very slight rise. It is believed that Flag 112/54 must be at or close to the lowest part of Madigan Gulf — and, indeed, of Lake Eyre North itself.

TABLE 1.

Volume of Madigan Gulf up to A.R.L. 98 ft.

Surface Level	Total Volume
A.R.L. 92 ft.	5,000 ac.-ft.
A.R.L. 93 ft.	40,000 ac.-ft.
A.R.L. 94 ft.	100,000 ac.-ft.
A.R.L. 95 ft.	200,000 ac.-ft.
A.R.L. 96 ft.	370,000 ac.-ft.
A.R.L. 97 ft.	600,000 ac.-ft.
A.R.L. 98 ft.	900,000 ac.-ft.

Figure 3 shows provisional contours of the bed of Madigan Gulf. It is based principally on the levelling survey, but it also makes use of other data on water limits observed from the air in the A.R.L. 95-98 ft. range. Too great an accuracy must not be expected, owing to the limited coverage of the surveys.

The volume of Madigan Gulf for levels up to A.R.L. 98 ft. was calculated from areas within the contours and Simpson's Rule (see Table 1). The total volume to that level is shown to be 900,000 acre-feet.

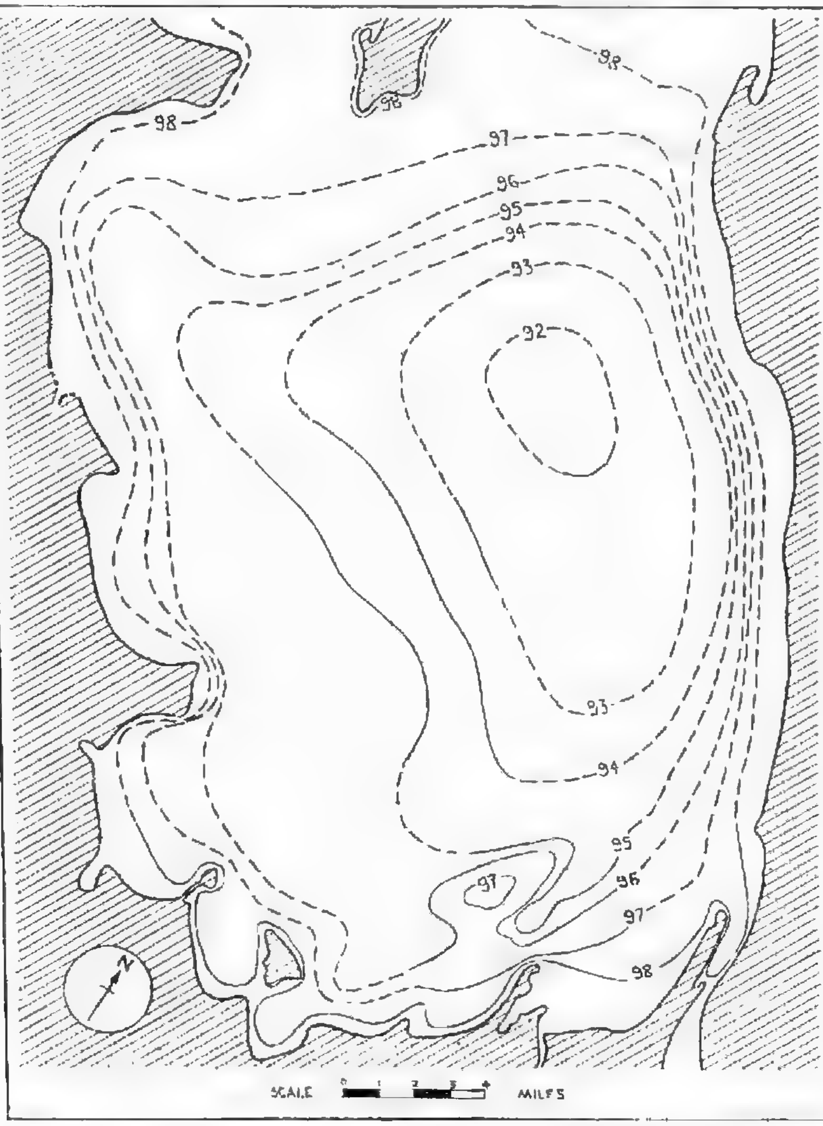


Fig. 3.—Tentative Contours of the Bed of Madigan Gulf.

THE SALT CRUST

Madigan was the first to examine the salt crust of Madigan Gulf (Madigan, 1930). He measured a thickness of 17 in. at a point which must have been close to location Flag 86/54. No thickness as great as this was measured in 1954.

The Surface Formations:

Madigan recognized a number of different types of salt crust which, from the shore, may be summarized as follows: The "piecrust" or "bull-dust" surface of the virtually salt-free lake bed near the shore; damp clay between this and

the salt crust; "pancake" slabs of thin salt left as remnants after solution by rain; tessellated salt with cracks, forming slabs with upturned edges; salt marked with polygonal cracks (only markings) with 2-3 ft. sides; salt with larger-scale arcuate buckling; large patches of dark-red, dirty salt; buckled slabs only 1-in. or so thick, with more firm salt below; and comparatively smooth and featureless salt. He described the general colour as "pink," and he ascribed the red colour of the upturned slab edges to blown red dust.

In 1953 the author examined salt formations in the vicinity of Kunoth Shoal at a time when practically all the crust was submerged by flood waters. The overlying lake water was a saturated brine. The salt thickness was measured beneath the water of the tongue between Prescott Point and Kunoth Shoal in three places. At about half-mile south of the subsequent year's Flag 4/54 location it was 5½ in. thick, with a plane of weakness (along which it parted when sampled) at 3 in. from the bottom. The bottom quarter inch or so was greenish, and the underlying bed was a pale-green mud. The upper surface of the crust was quite smooth and hard (as with all the submerged crust encountered in 1953). At this place the supernatant brine was 8 in. deep.

The salt was coarsely crystalline — like that made from sea water by the conventional solar evaporation process. Its bulk density was approximately 150 tons solid sodium chloride per acre-inch. Analyses of the salt and the brine above it are given in Appendices I and II.

The salt types observed in 1953 in the course of walking and wading near Prescott Point and Kunoth Shoal are as follows:

Wet mud surface above the level of the salt crust; similar, but with incipient polygonal cracking (see Plate IIa); shallow, scooped-out patches of the wet mud in the near shore area (probably caused by deflation when the lake is dry) raised island slabs of thin salt with dissolved-out areas in between (near water's edge—see Plate IIIa); smooth, thick crystalline salt covered with brine; roughly parallel, curled-up ridges of crust at eastern edge of shoal; banks of drifted disc-shaped crystals, each about the size of a shilling piece (see Plate IVa); isolated patches of very thin salt, like waterlily leaves (on crest of shoal — see Plate IIIb); and pudding-shaped salt excrescences from the flooded salt crust, projecting above the water surface.

The crest of Kunoth Shoal was apparently above the level at which the evaporating lake in 1952 would have begun depositing salt (Bonython, 1955 b). The ground here was higher than that crossed in 1954 at Flag 7/54. Salt-free wet mud — the first type of 1953 — was observed generally near the shore, e.g. in Level Post Bay; between the west side of Sulphur Peninsula and the salt crust; between Shelly Island and the main shore; and in the bay north-west of Pittosporum Head. Salt slabs with curled-up edges were uncommon in 1953.

A fuller study of the salt crust was possible in 1954. The surface layer had been laid down only a few months previously, and none was then submerged beneath water. A list of the different salt classifications is given in Table 2.

The lake bed outside the limits of the salt crust was much the same (Type 1a, 1b) as it had been in 1953, but rather firmer to travel on. The first part of the crust encountered — just beyond Prescott Point — was still in the form of ice floe slabs (Type 3), but the slabs themselves were now traversed by numerous, uneven cracks dividing them into irregular polygons; the edges of the polygons tended to curl up, and a feathery growth of efflorescent salt (Type 8 — see Plate VIa) protruded from the cracks. The white of the efflorescence contrasted with the pinkish, sometimes dirty, brownish-red, colour of the slabs. The latter formation (Type 5 b) was restricted to crust of thickness 1 inch or less. It is termed "crocodile-skin" salt. It was seen again on crossing Kunoth Shoal (see Plate 1 b); the polygons there were 3-4 ft. across, and the general colour was pale pink to off-white. As the crust thickened on either side of the shoal the cracking was less marked, and the polygon size decreased to a few

inches (Type 5 a). Types 5 a and 5 b salt were also seen near the shore at Pittosporum Head, and on the opposite side of the gulf near the north-east coast.

There was always a rapid transition from a crust thickness of about 1-in. to one of about 6-in. The surface of the thick salt was frequently smooth and featureless (Type 6 a), while at other times it might have a faint pattern of polygonal cracks (Type 6 b).

A salt formation first observed by the author in 1954, near Flag 10/54, was an island of rusty-red, cemented "drift" salt (Type 7 b) raised 3-6 in. above the general surface. It appeared to have formed during the evaporation of the lake waters from floating salt flakes which had become stranded against an

TABLE II
Surface Salt Formations

Type	Description
1 a	Wet, damp or dry mud surface above the level of the salt crust. It may have a powdery coating of small salt crystals, and the mud when dry may have a wrinkled, "pie-crust" appearance (see Plate Ia).
1 b	Like 1 a, but with incipient polygonal cracking (see Plate IIa).
2	Shallow, scooped-out patches in the mud of the nearshore areas (see Plate IIb).
3	Raised island slabs of thin salt, with dissolved-out areas in between—"ice-floe" salt (Characteristic of the edge of the main crust—see Plate IIIa.)
4	Patches of thin salt with curled-up edges occupying depressions like those of Type 2. Called "water-lily" salt; observed only on Kunoth Shoal, in 1953. (see Plate IIIb.)
5 a	Continuous, thin (1 in. or so) salt with incipient cracking into polygons 4-10 in. across.
5 b	Ditto, but divided by efflorescent cracks into polygons 3-4 ft. across. ("Crocodile skin" salt—see Plate I b.)
6 a	Smooth, thick salt crust; featureless (see Plate VIII a).
6 b	Thick salt, with a faint pattern of polygonal cracks.
7 a	Banks of drifted, disc-shaped salt crystals ("numulitic" drift salt) each about the size of a shilling piece (see Plates IV a and IV b); uncoloured.
7 b	Ditto, coloured on the surface bright rusty-pink, dirty-brown, etc. (see Plates V a and V b).
8	Snow-white, efflorescent salt bulging from cracks in Types 3, 5 b, 7 a, and 7 b (see Plate VI a).
9	Pudding-shaped mounds of salt projecting above the general salt surface—"ice-pudding" salt. (See Plate VI b.)

excrescence of "ice-pudding" salt (Type 9—see Plate VI b). Such an accumulation would be self-accreting once it had begun to form in shallow, salt-depositing brine. As well as stranding more floating crystals, the drift would also grow by further crystallization from the supersaturated lake brine. Beyond Flag 10/54 it was common to see several such islands at a time; those seen later were composed entirely of drift salt, without having any visible core. A good example of the latter—and a particularly striking sight—was such an island near Flag 37/54, 12 miles from Prescott Point (see Plate V a). It was 40 yards long in a northeast-southwest direction, and it curved gracefully in scimitar form. It consisted of "numulitic" drift salt, and it stood 3-4 in. above the general surface. The salt was snow-white within, but its upper surface was a bright, rusty pink. It gave the impression of having been coloured by an originally floating scum which had drifted against, and had become adsorbed upon, a salt bank at that time just showing above the water surface. The island was seen to be crossed at right angles by numerous, roughly-parallel cracks from which pure white efflorescent salt bulged (cf. Type 8). The cracks must have been formed after the lake had dried up. Chemical analysis shows the efflorescence to be 99½ per cent. sodium chloride.

The distribution of these salt islands varied over the area of the gulf, and in some places they were uniformly orientated. Many lay parallel to the contours of the bed, i.e. parallel to the shoreline of the shrinking lake remnant, but many were also at right angles to the contours. In some cases the formation was possibly influenced by the wind that had prevailed while this was taking place. They were not seen within one mile of the main shore (the nearest one to Prescott Point being four miles away), nor were they found at the lowest part of the gulf. Some islands were almost circular (see Plate V b). Those of the interior parts were the less highly coloured (Type 7 a). They probably correspond to the "arcuate buckling" of Madigan (1930); however, it seems that they were not formed by a subsequent buckling process, as he inferred, but instead they originated as a phenomenon of salt deposition by evaporation.

Drift salt crystals that had presumably settled on the surface of the main crust as the water dried up gave it a blistered appearance. These often occurred in strings, and in the form of serpentine drifts (see Plate IV b) which were probably embryonic salt islands.

The growing surface of the salt deposit in an evaporating salt lake or pond is inherently unstable (Bloch, 1951); since the supersaturation of the salting liquor must increase upwards towards the surface of the evaporating brine anything that raises part of the salt bed (e.g. a drift of loose crystals) or a foreign body projecting above it (e.g. a wind-transported roly-poly bush), will cause accelerated salt growth at that point, so producing excrescences frequently rising sharply from the bed. Salt "islands" and "ice-pudding" salt are respective examples of the growth resulting from this instability. By contrast, an unsaturated solution overlying a salt bed has a marked stabilizing effect upon it, planing the surface smooth in the manner that Bloch describes. There was little obvious evidence of this having occurred at Lake Eyre, some undercutting of mounds of "ice-pudding" salt by rain-diluted brine being possibly the only examples. A partial re-flooding of the crust by fresh waters, or a heavy fall of rain on the waters during the deposition phase, could have caused such planing of the crust, and although the former occurred in 1953, evidence of it is probably concealed by the salt subsequently deposited on top of any planed surfaces. The effect of rain on salt crust already high and dry is shown in the irregular dissolution in the "ice-floe" salt areas near the shore.

Cracking and buckling (see Plate VII) of the salt crust seem to increase with the elapse of time after deposition. Madigan probably saw the crust at least five years after its formation, when it was more buckled than in 1954. No doubt longer periods of weathering would further accentuate buckling, so that if left unflooded long enough it might eventually resemble the salt of the Lop plain in Sinkiang (*vide* Grabau, 1920) where the buckled crust assumes the shape of frozen waves of a choppy sea.

The different salt formations in Madigan Gulf have been classified and described in Table 2. In addition, mention should be made of another form of crystalline salt not often found naturally at Lake Eyre, and belonging more correctly to the laboratory. This is sodium chloride in long, needle-like or hair-like crystals sprouting from brine-saturated clay that has been allowed to dry for many days in still air. It has already been described by Fenner (1952). The author has commonly seen it on clay adhering to specimens of nodular native sulphur (Bonython and King, 1955).

Bores in the Salt Crust:

The salt crust was bored at 55 places along the surveying traverses, and also at some other places. A bore is designated by the serial number of the adjacent survey flag (e.g. Bore 50/54 for the bore at Flag 50/54). The top of the ground brine within the crust was usually close to the upper salt surface, in the lowest parts of the gulf it being practically at the surface and visible in

the bottoms of slight irregularities in the crust. The crust was nearly all firm and hard, and it often presented great resistance to the boring tool, but where the brine reached close to the surface the top inch or two of the salt was soft

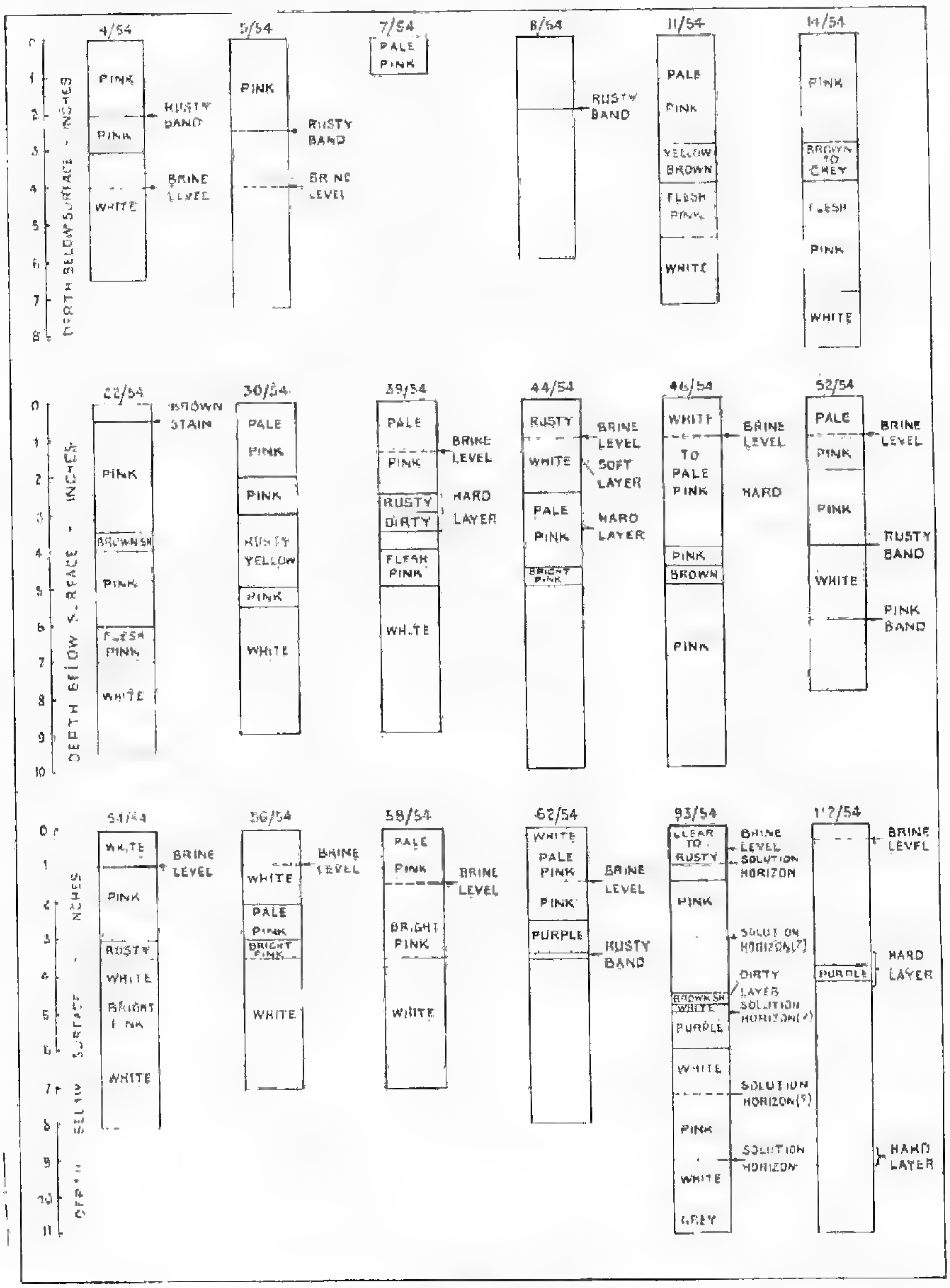


Fig. 4.—Logs of Bores in the Salt Crust.

and crushable, allowing one's boots to sink in appreciably and the jeep's tyres to sink more than an inch. The last effect, experienced at 25 miles per hour, was of sudden, intermittent collapsing of this top layer, giving the sensation that the wheels were about to break right through the crust; so marked was it

from Flag 110/54 onwards that for prudence the jeep was not taken past Flag 113/54. Brine was close to the salt surface in places other than the bottom of the gulf, viz. near Flag 99/54 and over much of the north-western part of the survey "box" (Flags 41/54-57/54). The ground brine surface had not reached a common level throughout the area of the salt crust. Apart from the irregularities described, its shape was that of a saucer slightly more flattened than the lake bed itself.

The operation of boring the crust with the hand tool revealed hard and soft layers at those levels where there appeared to have been a break in the progression of salt deposition; those places were characterised by occasional cavities due, perhaps, to partial dissolving-out of the salt, and were termed "solution horizons". Certain rusty and bright pink salt layers were regularly encountered in the borings. Figure 4 summarizes the logs of the salt crust bores. There is a certain rusty band in most of the logs belonging, it is conjectured, to a single epoch in the salt solution-deposition cycle. It occurs at 4-5 in. above the bottom of the crust in all logs except those for 79/54, 93/54 and 112/54. The latter three belong to the deep part of the lake bed, where the salt may possibly have had a somewhat different history: 5-6 in. above the base they show a striking band of purple-pink salt not shown in other logs, and this could possibly correspond to the missing rusty band.

A block of salt crust almost 1 ft. cube was obtained at Flag 93/54 by boring holes close together round the sides of a square (see Plates VIII a and VIII b).

Colouration of the Salt:

There were two types of colouration observed:

(a) The rusty-pink to dirty brown surface of the crust near the shore and of the "islands" (Type 7 b) in the interior of the gulf.

(b) The purple-pink stratum in the body of the salt crust.

Madigan recorded (a) as a discolouration of the buckled salt surface, and he ascribed it to red dust. The author obtained some bright red scum from the surface of drift salt on the edge of Kunoth Shoal in 1953, and as the result of the report by L. G. M. Baas-Becking, he was inclined at first to believe that Madigan's red colour was of organic origin. Baas-Becking's examination indicated the colour to be an organic pigment from or associated with the flagellate *Dunaliella salina*. The pigment was obtained as dark orange crystals after three recrystallizations from acetone. It was believed to be a caratenoid pigment, and this was confirmed by the salt having the odour of violets, assumed to be ionone — a breakdown product of carotenes. No iron was present.

However, samples of discoloured salt obtained in 1954 when the lake was dry had different properties. I. R. Kaplan examined discoloured salt crust from one mile north of Prescott Point, and he found the stain to be due almost entirely to iron oxide (200 p.p.m. Fe^{+++}), with a small proportion possibly due to *Bacterium halobium* and *Dunaliella* sp. Rusty red drift salt from the salt "island" near Flag 37/54 was examined microscopically by I. M. Thomas; he found no organic matter in it, but found what appeared to be red dust. S. M. Shephard found this salt to contain iron (300 p.p.m. Fe^{+++}).

The rusty-red colouration of the banks of drift salt therefore seems likely to be due mainly to red dust, initially trapped on the surface of the evaporating lake in a floating froth which was eventually carried by the wind to be stranded on one of the low banks of drift salt then beginning to emerge from the waters. (The author has commonly observed such a floating froth, containing clay material, on the surface of strong brine in certain reservoirs in a salt works.)

The surface salt colouration of Lake Eyre deserves further study, in the author's opinion. In view of the 1953 report of an organic colouring substance he is not entirely satisfied that all the surface stains are inorganic in nature.

The striking purple-pink colour (b) of the middle layer of the salt crust at Bore 93/54 was also studied by I. M. Thomas; by microscopic examination he found it to contain small, amorphous, mucoid masses which could have been of bacterial origin. No living flagellates were observed, and no development occurred on incubating the salt at 27 deg. C. in constant light.

THE QUANTITY OF SALT

The crust thicknesses measured in 1954 are shown in Fig. 2. The crust is believed to cover all Madigan Gulf within approximately the A.R.L. 97 ft. contour line. If lines of equal salt thickness are drawn, and a procedure somewhat similar to that described for finding the water volume in the gulf is used, it is found that the volume of the salt crust in Madigan Gulf is 1,800,000 acre-inches. The mean value of several determinations of the bulk density of the salt of the crust is 150 tons of sodium chloride per ac.-in., which makes the total amount of sodium chloride 270,000,000 tons.

An independent calculation of the salt tonnage has been made as follows:

The volume of brine in Madigan Gulf when filled to A.R.L. 98 ft. has been shown to be 900,000 ac.-ft. It was also shown (Bonython, 1955 d) that the salinity of the brine on 13th December, 1951, when the level was A.R.L. 98·1 ft., was 234 gm. sodium chloride per litre. So, assuming that the salinity when the level had fallen to A.R.L. 98·0 ft. was 240 g.p.l., we may calculate that the sodium chloride content of Madigan Gulf was 260,000,000 tons, which is close to the other estimate. A derivation from the above calculation is that the waters of the gulf should have been just saturated with sodium chloride (at 318 g.p.l.) when the volume had shrunk to 680,000 ac.-ft.; this corresponds to A.R.L. 97·3 ft, which is hence a fundamental level in reconstructing the sequence of events when salt is being deposited in the lake by evaporation of the waters.

It has been shown (Bonython, 1955 d) that when a plausible value is assumed for the total residual volume of the Belt Bay and Jackboot Bay basins for the December, 1951 epoch the total amount of sodium chloride in Lake Eyre North works out at approximately 400,000,000 tons. This strictly applies to the lake above the surface of the bed proper — the interface between the crust and the gypsum slush (ref. Bore 93/54). In the absence of a bore casing to prevent brine from above gravitating to the lower levels of Bore 93/54 it was impossible to tell whether the gypsum slush stratum in this bore was saturated with brine or not, but if it had been the matter would be of some significance. A rough estimate of the gypsum content of Lake Eyre is ten times the tonnage of the salt crust (or 4,000 million tons). However, some account has been taken here of the gypsum content of the surrounding dunes, and the quantity of gypsum beneath the lake bed would be rather less, say half. Gypsum slush with 50 per cent. voids filled with saturated sodium chloride solution will hold 0·15 tons sodium chloride for each ton of gypsum, so that if 2,000 million tons of gypsum exist beneath the lake bed it could mean that the sodium chloride content of the lake is nearly double that already estimated. In view of the uncertainties the sodium chloride content of Lake Eyre will be taken as that existing above the lake bed, viz. 400 million tons.

The content of magnesium and potassium salts present above the lake bed can be derived from the volume and composition of the lake waters during 1950-1 (Bonython, 1955 d), assuming that the salts which would precipitate on taking the brine to dryness are those arbitrarily assigned in the analyses. Owing to doubt and the paucity of data concerning potassium content a Mg^{++}/K^{+} ratio of 5/1 is taken. The quantity of magnesium and potassium salts works out at approximately 7 million tons.

THE DEPOSITION OF SALT BY EVAPORATION—THEORY AND OBSERVATION

The theory of the deposition of sodium chloride from an initially saturated brine is simple, and it is confirmed by experience in the field of commercial production of salt from sea water by solar evaporation. Supersaturation produced by evaporation at the brine surface causes a progressive growth of salt crystals on the floor of the pond. A small proportion also crystallizes at the brine surface, and most of this sinks to become part of the floor crust. As evaporation rate is practically constant over the lake surface, regardless of the depth, the rate of salt deposition per unit area will likewise be constant. However, in the case of a saucer-shaped lake the shallower parts will gradually be left high and dry, as the level falls, and the salt deposit on those parts will clearly then cease to grow; those parts still submerged will continue to gain in salt thickness. Hence the initially shallowest parts of the lake will finish having the thinnest salt deposit, and the deepest parts the thickest deposit.

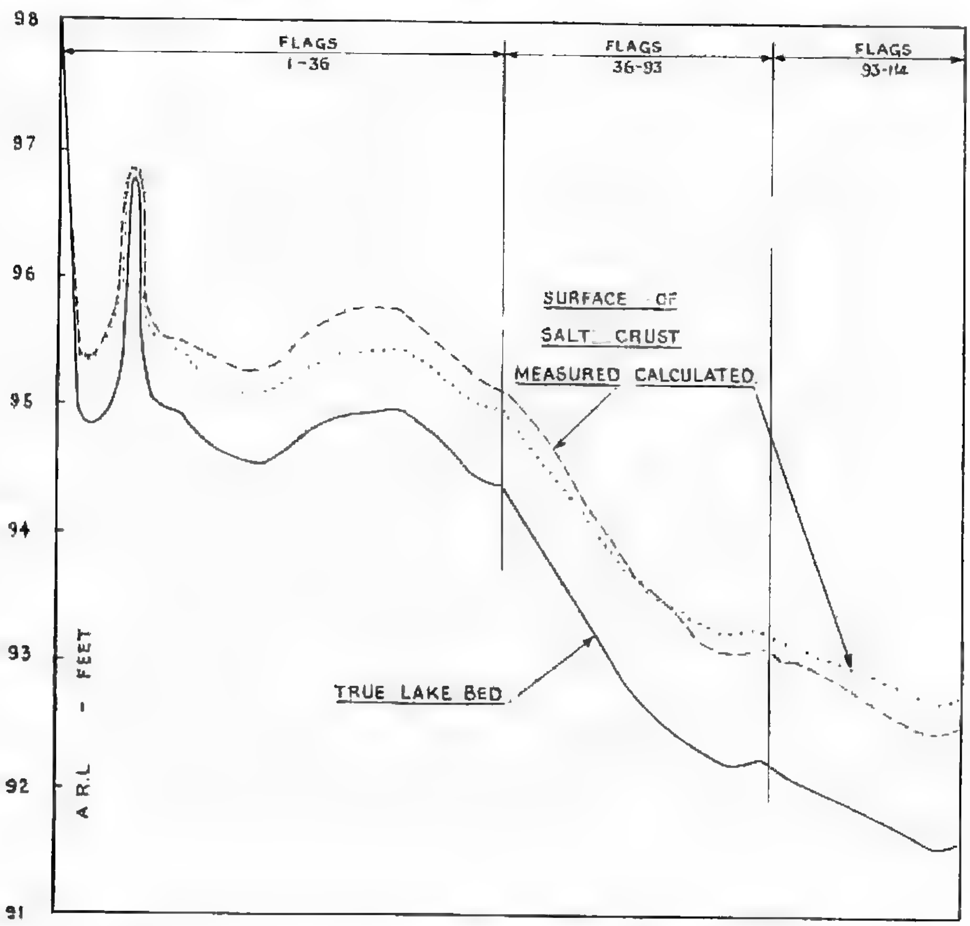


Fig. 5.—Cross-section of Part of the Lake Bed and Salt Crust.

The evaporation of 100 cm. of saturated brine will give a salt deposit 20 cm. thick if the bulk density of the latter is 1·5 gm. NaCl/ml. (approx. 150 tons/ac.-in.). Thus the simple but important conclusion is drawn that the thickness of the salt crust should be one-fifth of the total depth of saturated brine originally overlying the spot. The evaporating brine in Madigan Gulf first reached saturation when the surface fell to A.R.L. 97·3 ft., so theory says

that the subsequent salt crust thickness at any point should be one-fifth of the distance of bed below this fundamental level. This is put to the test in Figure 5 where actual and theoretical salt thicknesses are plotted. The agreement is fair for parts of the gulf where the lake bed is below about A.R.L. 94 ft., but at higher levels the observed thickness tends to exceed the theoretical thickness. The latter effect is marked on the gentle rise surveyed between Flags 20/54 and 30/54.

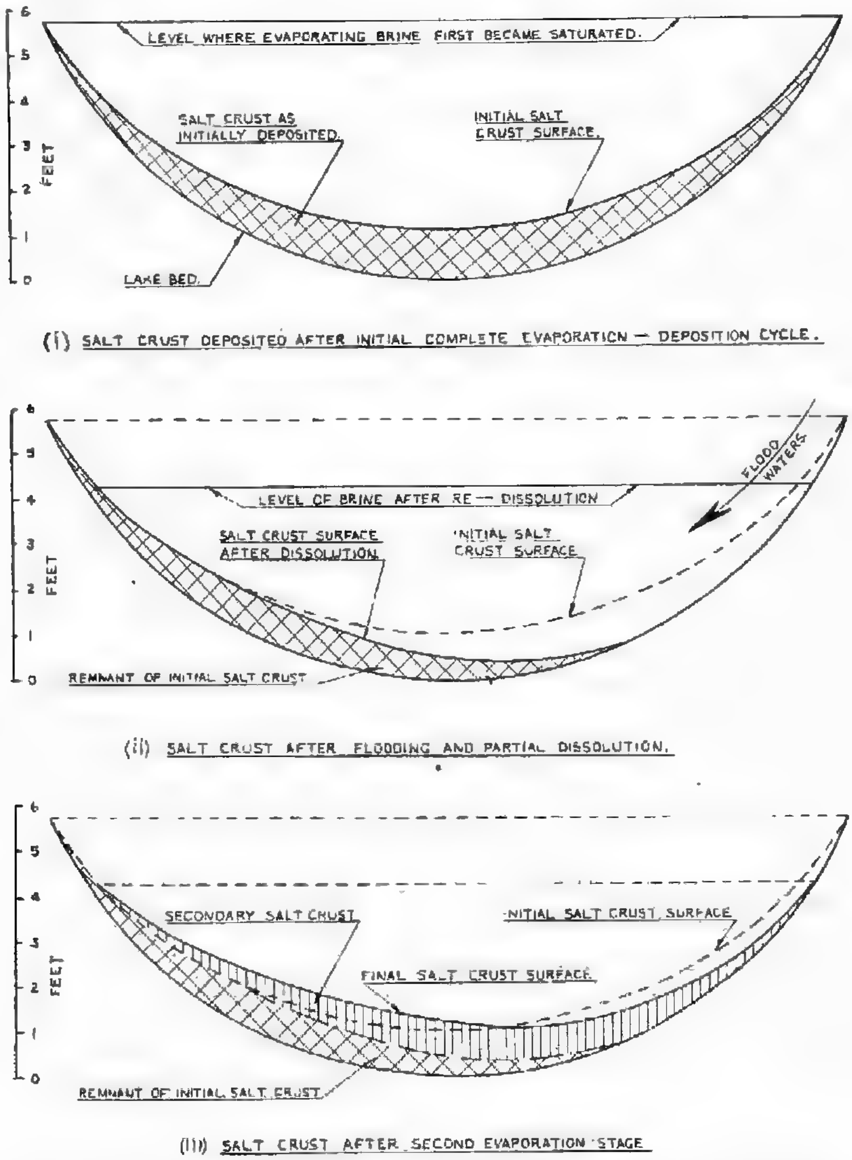


Fig. 6.—Theoretical Effect of Subsequent Flooding on Ultimate Salt Crust Profile.

The explanation may be found in the actual history of the interrupted deposition cycle. After the 1951-2 drying-up phase there was a further cycle in 1953 with the partial dissolution of the crust followed by the re-deposition of the dissolved salt. It is significant that in May, 1953, the lake water, which stood at A.R.L. 95·8 ft., was a saturated brine round the Kunoth Shoal area, but off Artemia Point it was only half saturated. It seems that the more-or-less-

fresh floodwaters entering Madigan Gulf from the north-west had become saturated in their passage across to Kunoth Shoal in the south-east. Much salt would have been dissolved where the water first impinged on the north-west salt crust, but little or none would have been dissolved in the south-east salt crust. Actually, about 50 per cent. of the total salt in the gulf must have been dissolved. The picture is therefore one of a salt crust that has suffered uneven dissolution overlain by what must eventually have become an evenly mixed, saturated brine. After evaporation had re-deposited the dissolved salt on top of the partly-dissolved crust the picture of total crust thickness must have been different from that at the end of the original deposition cycle. Figure 6 illustrates this by showing the theoretical salt crust thicknesses in an idealized lake that had been filled originally with saturated brine to a level equivalent to A.R.L. 97·3 ft., and which then dried up; subsequently it was flooded from one side with fresh water to a level equivalent to A.R.L. 95·8 ft., when some 50 per cent. of the salt was dissolved, and finally the latter was re-deposited by evaporation. The final salt thickness distribution is significantly different from that of the initial deposit.

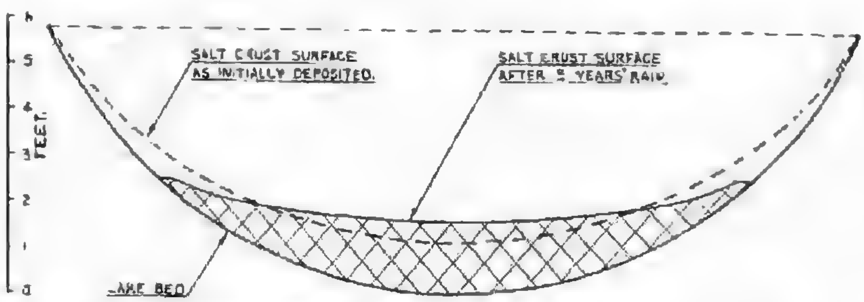


Fig. 7.—Theoretical Effect of Rain on Ultimate Salt Crust Profile.

Other facts which could help to explain the differences between the theoretical and observed salt thicknesses in Figure 5 are, firstly, that Kunoth Shoal (at Flag 7/54, for instance) was above the 1953 flood level and hence should not have been affected by that flood, and secondly, that the salt crust on the rise in the survey line between Flags 20/54 and 30/54 would have been only just awash in 1953 — and with saturated brine, too — so that the thickness there may have been disproportionately increased both by the beaching of "drift" salt and by the evaporation of successive wettings of the surface by seiches (*vide* Bonython, 1955 c; Penman, 1955).

A deposition effect of longer range is that of several seasons' rainfall on the crust over a series of unflooded years, each followed by a drying-up phase. The ground brine formed when each rain dissolved some of the salt would tend to migrate towards the lowest part of the basin before drying up; this would be expected to reduce the crust thickness at the outer perimeter and to increase it towards the centre. The surprisingly-large crust thickness of 17 in. reported by Madigan could be explained in this way. Figure 7 attempts to show the effect of five annual rainfalls each totalling 4 in. on the salt crust of an idealized lake bed. The brine resulting from each annual rainfall is supposed to gravitate to a central pool before evaporating to dryness. (For simplicity the possible retention of ground brine in the outer parts of the crust is ignored.) The salt crust, initially 14 in. thick in the centre, is seen to increase to 20 in. there. Such a long-period process could have occurred in the dry years preceding Madigan's investigation in 1929. Madigan found Kunoth Shoal salt-free at the place where he crossed it in 1929; since this place was just north of the subsequent location of Flag 7/54, where the salt was 1 in.

thick in 1954, the two observations appear at first sight to be in conflict. However, the removal of this thin crust can be explained simply by the rain dissolution theory — in fact. little more than one average year's rain would be capable of removing the one inch salt layer and carrying it in solution to the deeper parts of the gulf. Therefore, it is to be expected that Madigan should have found the shoal salt-free.

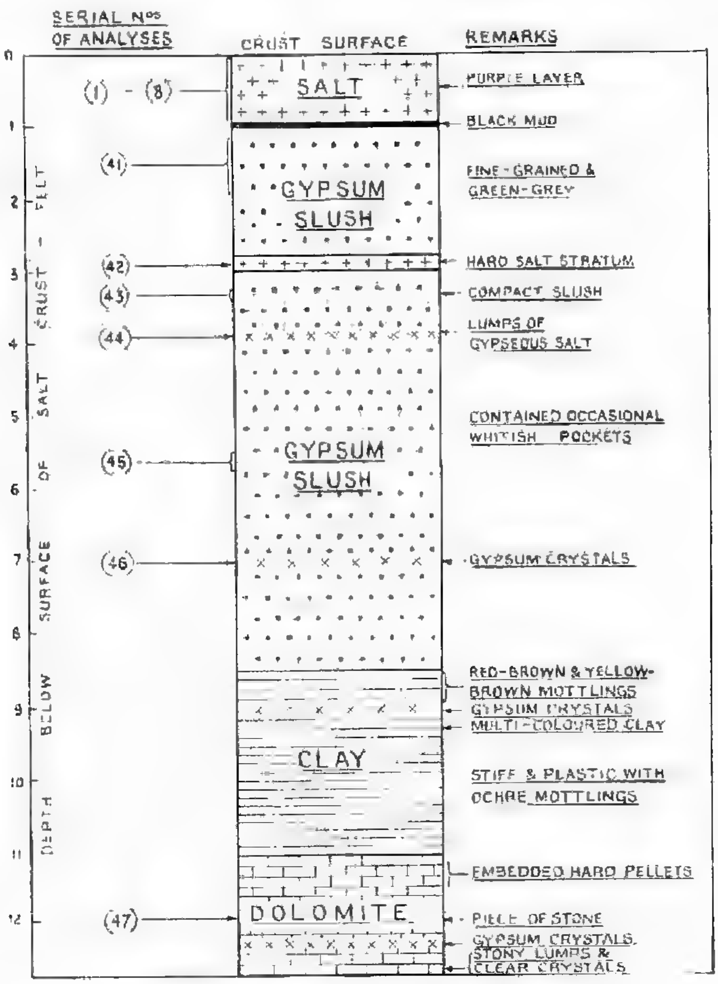


Fig. 8: Vertical Section at Bore 93/54.

A BORE IN THE BED OF MADIGAN GULF

A hand bore (Bore 93/54) was put down near the lowest part of the lake bed where the level was A.R.L. 92·2 ft., during 31st August and 1st September. 1954. The depth of 12 ft. 8 in. was reached. The log is shown in Figure 8.

The boring tool used at first was a 4-in. posthole digger with tubular shaft extensions. It had a cutting head suited to boring crumbly materials (viz. with several sharp, inclined teeth set round the periphery). At 5 in. below the salt surface a 1-in. band of purple-pink salt was found. The usual half inch of black mud was found beneath the 11 in. crust, and then at 12 in. a fine-grained. green-grey slush was entered; it proved to be mainly gypsum (see analyses 40, 41), and the tool penetrated it with ease. Then at c. 2 ft. 10 in. an extremely hard, thin layer of salt was struck. Although this must have been only 1 or 2 in. thick, it was not possible to bore through it directly, and it was

pierced only by driving a length of ¾-in. steel rod through in several places by hammering its upper end. Analysis (No. 42) showed the layer to be predominantly sodium chloride. Then followed bands of soft and hard gypsum slush, the layer at 3 ft. 8 in.-4 ft. containing coarse lumps of sodium chloride (see analysis 44). From 4 ft. down to 8 ft. 6 in. the material was all green-grey gypsum slush with occasional pale pockets of the same composition.

At 8 ft. 6 in. a plastic, green-grey clay containing inclusions of a yellow ochre colour was entered, and to penetrate it successfully it was necessary to change the cutting tool for one of the "Iwan" type which has two curved, tapering cutting blades from which adhering clay can be cleared readily. At 9 ft. the clay became extremely stiff and, together with yellow-brown mottlings, it contained embedded gypsum crystals. At 9 ft. 3 in. the clay became strikingly multi-coloured (grey, green-grey, purple-grey and brown, with some ochre mottling), while thereafter down to 11 ft. it was again stiff and green-grey with some mottling.

There was a change at 11 ft. to 11 ft. 4 in. when a substance like a very stiff, white pipe-clay was entered; it later proved to be dolomite. It contained numerous grain-size pellets of hard stone. Even the Iwan cutting head failed to make appreciable headway here so, on the second day of boring, a 2-in. auger bit was substituted. It still involved some 10 minutes' hard work by two men for each 3-in. of downward progress achieved. The same rotten dolomite continued to the bottom of the bore at 12 ft. 8 in. It was found to contain increasing numbers of hard stone lumps (dolomite) and some gypsum crystals. The plastic material peeled from the spiral grooves of the auger was dry within; this contrasted with the wet state of the gypsum slush from the higher levels.

The chemical composition is detailed in Appendices I and III. The salt crust was principally sodium chloride, the black mud beneath it was mainly calcium sulphate, while the solids content of the 7½ ft. of slush was calcium sulphate. (Although the last analysed c. 10 per cent. sodium chloride (see analyses 40, 41, 43 and 45) this was mainly present as brine which may well have gravitated from the salt crust level during boring.) X-ray examination of the slush by K. Norrish and L. Rogers of Division of Soils, C.S.I.R.O., showed the calcium sulphate to be in the form of gypsum. By this means they also showed the 2½ ft. clay layer to contain the minerals kaolin, quartz, palygorskite and jarosite with gypsum as the main constituent of the white and yellow mottlings. The dolomite layer, a sample of which was analysed by the South Australian Mines Department, was chemically close to the theoretical composition, but it also contained small amounts of silica, alumina and ferric oxide (see analysis 47). X-ray examination of this layer confirmed the presence of dolomite, quartz, kaolin, illite, palygorskite and gypsum.

The potassium minerals, jarosite and illite, are again referred to in a later section.

THE CHEMICAL COMPOSITION OF THE SALT AND BRINES

The chemical analyses of the salt and brine samples are detailed in Appendices I and II. Analyses reported by Madigan (1930) and Fitzpatrick and Strong (1925) are also included for reference. The salt crust is almost entirely sodium chloride, with gypsum as the only significant impurity (Bonython, 1955 d). The small amounts of magnesium and potassium salts are almost certainly present entirely in solution in the brine wetting the salt crystals (the crustal salt is almost invariably damp to saturated with ground brine).

The Calcium Sulphate Content:

The composition of the lake brine before salt deposition began shows that the resulting deposit should contain overall about 2 per cent. of gypsum. The distribution of the gypsum content through the salt crust shows a smaller range

horizontally than it does vertically. The large vertical range reflects both the changing conditions during the original deposition process and the effects of the subsequent partial dissolution and re-deposition. Figure 9 shows the vertical distribution at one of the bore locations. A high gypsum content seems associated with the early part of a deposition stage; Bore 93/54, for instance, shows definite evidence of two superimposed cycles. The highest gypsum concentration in this bore appears at the "solution horizon" 5 in. down, and this probably corresponds to the end of the partial dissolution phase and the beginning of the second deposition phase. Undissolved gypsum from the dissolution stage would tend to sink and accumulate on the bottom, so forming a gypsum-rich band.

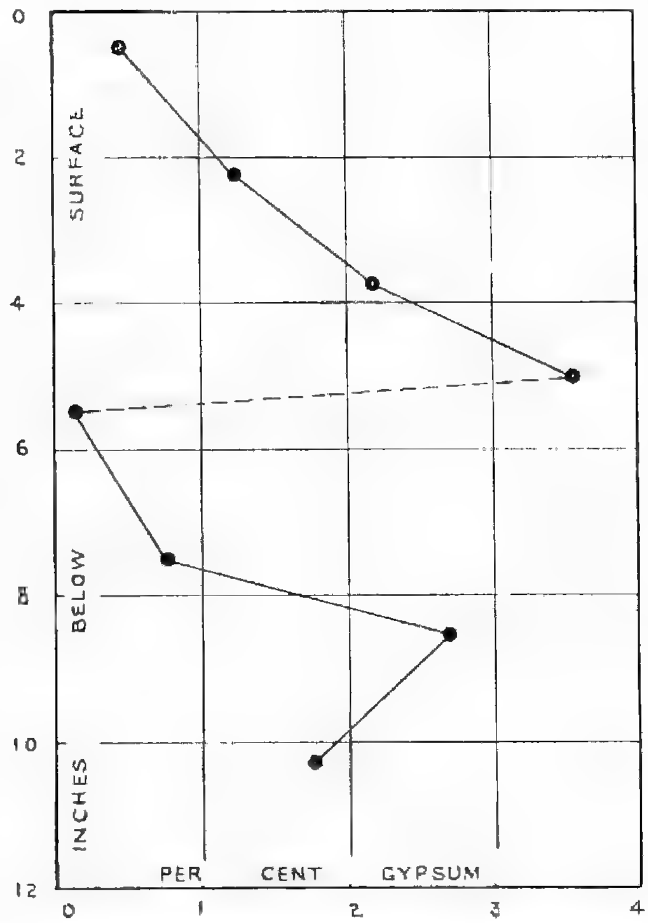


Fig. 9.—Gypsum Content of Salt Crust at Bore 93/54.

Experience in commercial solar salt production shows gypsum to be present in such a form that on dissolution of the sodium chloride, or even on handling the crumbled crust, the gypsum frequently segregates as a "slime" of small crystals. It is therefore difficult to obtain representative samples of salt for gypsum assay by any method that disintegrates the salt crust, such as boring it, particularly if the crumbled crust has to be handled in contact with ground brine. The previously quoted gypsum contents of Lake Eyre salt (Bonython, 1955 d) are now thought to be erroneous for this reason. The only reliable samples for gypsum determination were those obtained in the laboratory from blocks of salt lifted integrally from the salt crust (cf. the block from Bore

93/54). However, even in the latter case there is some doubt concerning the purple-pink layer at 5-6 in. which crumbled when the block was lifted. It must not be overlooked that some downward migration of the gypsum "slime" might even occur through the pore spaces in the original, undisturbed salt crust in the midst of the deposition phase.

The gypsum content of nummulitic drift salt (Type 7) is very low (see analysis 11), as might be expected in salt initially forming on the water surface. In contrast, the gypsum content of the weathered, thin salt crust (ice-floe salt—Type 3) near Prescott Point (see analysis 12) is over 4 per cent. This could have come about by selective removal of salt by rain wash, or to inshore gypsum migrating lakewards under the influence of wind and water. Efflorescent salt (Type 8) had a gypsum content more consistent with the composition of the brine in contact with the salt crust.

The sulphate content of the solid salt samples is generally in excess of that necessary to satisfy calcium, and occasionally in excess also of that to satisfy magnesium. In the first instance it means that the magnesium salt which would first separate on desiccation would be the sulphate; in the second instance it means that some sodium sulphate should separate, too. The second tendency is shown for 7 of the 8 levels in the solid salt from Bore 93/54 (see analyses 1-8), but the sulphate excess over magnesium is usually so small as possibly to be ascribed to small inconsistencies in the analysis. However, at the 8-9 in. level (see analysis 7) the large content of 2 per cent. Na_2SO_4 is indicated, and no explanation for this can be advanced.

The calcium sulphate content of the 1950-1 lake waters enables one to calculate that gypsum separation probably began only shortly before the separation of sodium chloride (i.e. at about the end of 1951).

The calcium sulphate content of the May, 1953, lake brine from Artemia Point (see analysis 31) was nearly at saturation value, but it was at only half that value in the supernatant brine near Kunoth Shoal (see analyses 29 and 30). The ground brines from the salt crust in 1954 showed even lower values. It seems likely that brine found in or overlying salt in Lake Eyre is always unsaturated with respect to calcium sulphate, and this could be so if the brine was formed by dissolution of some of the salt crust, the gypsum content of the latter either being insufficiently high, or else some of the gypsum "slime"

TABLE 3.

Description of Brine Sample	Mg^{++}/K^{+} Ratio
Centre of Madigan Gulf—December 1929	5/1
Level Post Bay—May 1951	32/1
Kunoth Shoal—May 1953	10/1
Artemia Point—May 1953	8/1
Centre of Madigan Gulf—August 1954	4/1
Standard Sea Water (for comparison)	3·3/1

escaping dissolution itself, so failing to saturate the brine. It may be supposed, therefore, that the 1954 ground brines were not a pure evaporation residual, but contained a component due to dissolution of the salt by rain. The salt crust could hinder the brine above or in it reaching equilibrium with the gypsum slush of the lake bed.

Brines from holes in the margin of the lake bed outside the salt crust (see analyses 32 and 38) are unsaturated with calcium sulphate. The conditions there are not understood.

The Magnesium and Potassium Salts Content:

These are probably almost always present in the dissolved state in the Lake Eyre salt and brines. Magnesium and potassium concentrations probably vary together; Table 3 shows this only very roughly to be true, an exception being the May, 1951, brine.

Only a limited number of potassium determinations were made; in other cases the content must be inferred from the magnesium content.

The magnesium (or potassium) content of a solid salt sample is meaningless without the water content being known, because these salts are present only in solution. The significant factor is therefore the magnesium content of the ground brine. The Mg^{++} content of the 1954 ground brines varies from 3·4 gm./l. in Bore 4/54 near the shore to 6·6 gm./l. in Bore 93/54 at the bottom of the gulf. This shows that there is a tendency for the residual evaporation liquors to accumulate at the centre of the gulf basin, and this in turn implies lateral mixing of the lake brine during the drying-up process. There could also be a subsequent migration centrewards of the ground brine in the salt crust. Madigan's 1929 brines from the salt crust show a very similar magnesium disposition to those of 1954 (see analyses 33-37).

The story of the magnesium content of the lake waters during the 1950-2 drying-up (see analyses 25-28) is a straightforward one. Concentration of the waters by evaporation increased the Mg^{++} content from 0·15 gm./l. in October, 1950, to 0·82 gm./l. in December, 1951. It is supposed that then the lateral distribution through the lake would have been quite even. This was not so in the case of the brines supernatant on the salt crust in May, 1953, because the final drying-up in 1952 had probably brought about a segregation of Mg^{++} in the central parts. In 1953, while the Mg^{++} content was 1·8 gm./l. in the tongue of water between Prescott Point and Kunoth Shoal (see analysis 30), it was up to 2·2 gm./l. at the north-east tip of Kunoth Shoal (see analysis 29) which was nearer the interior of the gulf.

The Ground Brine From Bore 93/54:

The most highly concentrated remnant of the lake waters was the brine (see analysis 36) from the salt crust at Bore 93/54. However, although this had the highest Mg^{++}/Na^{+} ratio (55/1000) of any Lake Eyre brine, it was much lower than a typical "bittern" from commercial salt-making operations where frequently the Mg^{++}/Na^{+} ratio is 660/1000. The ground brine obtained from the bottom of Bore 93/54 was identical with that from the salt cru t above, and it seems clear that it had merely gravitated from the upper level during the boring. The dry state of the dolomite bed supports this view.

THE ORIGIN OF THE SALT

Lake Eyre contains approximately 400 million tons of sodium chloride. The gypsum content must be of the order of ten times this quantity, while magnesium and potassium salts together would amount to about two per cent. of the sodium chloride content. Table 4 sets out these figures:

TABLE 4.

Substance	Tentative Tonnage
Gypsum	(4,000 million) tons
Sodium chloride	400 million tons
Magnesium and potassium salts	(7 million) tons

While most of the gypsum forms the lake bed itself, or else exists in the dunes surrounding the lake, the contents of sodium chloride and of magnesium and potassium salts are considered restricted to material occurring on or above the lake bed.

Possible Sources:

The salts of Lake Eyre may have originated in various ways. The source may have been:

(1) The salts of a relict sea or lake.
(2) Connate salts weathered out from old marine sediments.
(3) Dissolved solids in waters escaping from the Great Artesian Basin.
(4) Wind-borne oceanic salts finally trapped in the Lake Eyre drainage basin.

The theory of a relict sea or lake is incompatible with the accepted geological history of the area in which the centre of the continent, once occupied by the sea, was later occupied by a fresh water lake. During the pluvial Pleistocene times the lake must have overflowed to the ocean, and in its so doing the continual flushing must have prevented any accumulation of salts forming or remaining from earlier times. Any accumulation must have taken place since the Pleistocene — after the lake stopped overflowing.

The connate salts source is a possibility, for it may be calculated that an area of 100,000 square miles of exposed marine sediments containing 1 per cent. sodium chloride and weathering at the rate of 0·001 in. per year will yield the 400 million tons in as short a period as 6,000 years. Similarly, in considering the "mound springs" of the Great Artesian Basin as the source, a spring flow of ten million gallons per day of water containing 1 gm. sodium chloride per litre would result in the same accumulation in 25,000 years.

The most likely source is oceanic salts carried inland by wind and brought down by rain to become trapped in the basin of inland drainage. This is the "cyclic salts" process now recognized as occurring over most of the land areas of the globe, but in enclosed basins of inland drainage the cycle is broken by the salts being prevented from returning to the ocean, and so they accumulate on the land. Over the Lake Eyre Basin there must be an annual fall-out of not less than 1 lb. sodium chloride per acre of catchment, or a total of 150,000 tons per annum. 400 million tons would accumulate in a mere 3,000 years. The Lake Eyre salt deposit could have been derived from any or all of sources (2), (3) and (4). It is likely that they have all contributed some of it, but the oceanic salts source is the largest. Rivers that regularly or periodically feed Lake Eyre, like the Cooper and the Diamantina, contain sodium chloride in solution to the extent of about 15 mgm. per litre. Very few analyses of these waters are available — none is known of for these rivers in the South Australian part of their courses* — but a few have been located in Queensland by W. H. R. Nimmo and communicated to the author (see Appendix IV), and it is from these that this salt content has been derived.† If it is assumed that the 25 million acre-feet of water that probably flowed into Lake Eyre in 1949-50 had this salinity the corresponding intake of salt becomes 450,000 tons. This seems in keeping with the intake to be expected from the cyclic salts source, bearing in mind that at the times of these exceptional river floods several years' cyclic

* The first South Australian analysis subsequently became available, and has been included in Appendix IV. It is for Cooper's Creek in November, 1955, soon after the peak of a large flood entering Lake Eyre. The high and predominating NaCl content contrasts with those of the Queensland data, but it has the effect of further highlighting the disparity between the actual quantity of salt in Lake Eyre and the amount of the accumulation to be expected from annual intakes.

† The figure has been arbitrarily reduced to allow for the fact that most of the samples were taken at times of low flow.

salts supply temporarily accumulated throughout the catchment area is likely to reach the lake at once.

The puzzling feature revealed by the foregoing figures is the *smallness* of the sodium chloride tonnage found in Lake Eyre, for in the arbitrary period of 50,000 years the sodium chloride accumulation possible from the cyclic salts source would be 7,000 million tons even with the conservatively low annual increment assumed. A continual wastage of the accumulation seems to be the only possible explanation for the comparatively low tonnage actually found in Lake Eyre.

The Composition of the Salts

The salts in Lake Eyre are present in quite different proportions to those in the ocean, and also to those in solution in the incoming river waters. Analyses of the latter show calcium carbonate to be the predominant constituent, with sodium chloride and calcium sulphate next in importance. Magnesium has not been determined in most of the analyses available, but in other respects the composition has little resemblance to that of the oceanic salts. This does not necessarily rule out cyclic salts as the main source for considerable changes in composition are known to occur quite early in the cycle. Lockhart Jack (1921), who studied this phenomenon near the South Australian coast, found that the composition of the dissolved solids in rain water rapidly lost resemblance to that of the parent sea water after storage in various sorts of tanks, and Anderson (1941) for a similar reason was obliged to trace salts from rain water to those present in natural surface waters by assuming that the chloride content was the only reliable criterion of oceanic origin.

Madigan (1930) noted the paucity of magnesium and potassium in the Lake Eyre salts, and he wondered whether plants, for instance, could have removed those cations from the surface waters during their passage across the drainage basin to Lake Eyre. This is in line with present day thought on the selective removal of certain elements from natural waters by cation-exchange processes in soils. Goldschmidt (1954) describes how certain cations, including K^+ and Mg^{++}, are removed preferentially to Na^+ by clays etc. It is also possible that removal of these cations could have continued in the lake itself.

Incidentally, the presence of much calcium carbonate in the incoming river waters suggests that large quantities must precipitate when these waters mix with the saline lake waters. Such an effect occurs in the Great Salt Lake, Utah (Grabau, 1920). Madigan Gulf is remote from such mixing places, except for the Frome estuary, but there must be lime deposits near the Cooper mouth and along the Warburton Groove still awaiting investigation.

Segregation and Possible Wastage of the Accumulated Salts:

The salts content of Lake Eyre is smaller than that which might be expected to have accumulated over a feasible period of geological time from several sources, so some avenue of wastage of the accumulation should be sought. Further, the salts are present in quantities the magnitudes of which are in the same order as the probable order of deposition of the same salts from sea water, or natural brines, for instance, and in the inverse order of their solubilities in water. If a wastage is occurring it seems that the less soluble salts are those which suffer the least wastage, so enabling them to form a larger fraction of the accumulating residue than they constituted in the incoming stream; the inverse would hold for the more soluble salts. This effect would be explained by a segregation process wherein the less soluble salts, being the first ones to be precipitated from an evaporating solution and the last ones to re-dissolve following any sort of flooding of the salt accumulation by fresh waters, would exist in the solid state for a greater proportion of the time than the more soluble salts. For example, consider Lake Eyre in 1954; most of its gypsum and sodium

chloride was present in the solid state, while probably all the magnesium and potassium salts were present in solution. Such a condition would favour separation of the solid and liquid phases — by seepage of the latter, for instance. If the lake were to dry up completely the magnesium and potassium salts would be the last substances to precipitate. If a dissolution then began these salts would be the first to dissolve. Also, we know of a recent flooding of the lake when all the sodium chloride dissolved, but only a minute fraction of the calcium sulphate went into solution.

We can therefore say that under the range of conditions that we know the lake contains—

(a) its gypsum in the solid state *all* of the time;

(b) its sodium chloride in the solid state *most* of the time; and

(c) its magnesium and potassium salts in the solid state for *not any* of the time.

As a refinement of (b), a small proportion of the total sodium chloride is, in fact, in solution all of the time.

If, therefore, we suppose that salts present in solution can be lost in some way, then we can conclude that the rate of wastage of gypsum should be negligible, that of magnesium and potassium salts should be considerable, while sodium chloride should waste at an intermediate rate. Loss by the downward seepage of solutions seems a plausible theory, but if it is occurring the lost solutions should not have travelled far and it should be possible to find them. However, as we know practically nothing of the region beneath the lake bed we are unable to say whether the facts confirm or confound this theory. Elsewhere the author has commented on the dryness of the dolomite bed beneath the centre of Madigan Gulf, and this might be interpreted as evidence against the seepage occurring. Another line of thought is that the very considerable tonnage of magnesium that must be present in the dolomite bed might have been placed there by a chemical reaction between the "missing" magnesium of the lake deposit and what was originally a calcium carbonate deposit beneath it. Continuing this line of thought, the "missing" potassium of the lake deposit could possibly be identified with the potassium components of the jarosite in the clay stratum and the illite in the dolomite stratum of Bore 93/54.

The liquid component of the salt crust might be lost in a quite different way, such as that postulated to occur in some Asian lakes (Graban, 1920). Here capillarity takes the solution to the surface of the salt crust whence wind carries it away either as a powdery efflorescence or adsorbed upon dust particles which had settled on the damp surface and had subsequently been carried aloft once more. This theory, while tenable for small, isolated salinas, is hardly tenable in the case of Lake Eyre where the dust would be likely to settle again within the inland drainage basin and so return again to the lake in a secondary cycle of migratory salts. The mechanism of the "wastage" phase of the theory thus must remain a matter of conjecture.

The theory here presented of the occurrence of the salt deposits in Lake Eyre is one in which a stream of what is principally airborne and surface-waterborne oceanic salts constantly enters the lake, and another stream, of different composition to the first, constantly escapes from it, while in the lake itself lies a certain "stock" of salts reflecting the equilibrium between the two streams. The composition of the stock is likely to have little resemblance to those of the incoming and outgoing streams as regards the proportions of the specific constituents, although the same constituents in greatly differing proportions are likely to be found in all three. The assumption that all the calcium sulphate accumulates in the lake, and none is lost, makes the age of the deposit 500,000 years if the annual intake of oceanic sodium chloride (with its associated calcium sulphate) is taken as 1 lb./acre/year in the Lake Eyre catchment basin. If,

however, this annual increment of sodium chloride is still taken, and then the gypsum content associated with it in the incoming surface waters is calculated according to the $CaSO_4/NaCl$ ratio revealed in Appendix IV (viz. 1·3/1) the age derived from the gypsum accumulation becomes 20,000 years.

The time that has elapsed since Lake Eyre ceased overflowing to the ocean could reasonably be expected to fall between these limits.

ACKNOWLEDGMENT

The author acknowledges with thanks the invaluable help of Mr. K. Peake-Jones and Mr. W. G. Fenner, the latter's painstaking survey work forming the main basis of this paper.

He also thanks Messrs. A. D. P. Dyer, D. King, I. R. Kaplan, A. C. I. Adams, J. R. Bryan, J. Fuss, G. W. Harris, R. A. Lawson, R. B. Norton and A. R. Russell who took part in the 1953 and 1954 expeditions. Messrs. T. W. Dalwood and T. R. Frost of the South Australian Department of Mines, and Mr. S. M. Shephard for carrying out analyses, Dr. K. Norrish and Mrs. L. Rogers of the Division of Soils, C.S.I.R.O., for measuring X-ray powder diffraction patterns of bore samples, Prof. L. G. M. Baas-Becking of the Division of Fisheries, C.S.I.R.O., and Mr. I. M. Thomas of the Department of Zoology, University of Adelaide, for making microbiological studies of salt and mud samples, and Mr. W. H. R. Nimmo of the Irrigation and Water Supply Commission, Queensland, for supplying data on the composition of river waters.

He further acknowledges the help of I.C.I. Alkali (Australia) Proprietary Ltd., and of the Director and Mr. D. King of the South Australian Department of Mines for lending equipment, and he is grateful to the Governors of St. Peter's College, Adelaide, who donated £40 towards expenses.

REFERENCES

Anderson, V. G., 1941. The Origin of the Dissolved Inorganic Solids in Natural Waters with Special Reference to the O'Shannassy River Catchment, Victoria, J. Aust. Chem. Inst. 8 (6): 130-150.

Baas-Becking, L. G. M., and Kaplan, I. R., 1955. The Microbiological Origin of the Sulphur Nodules of Lake Eyre, Trans. Roy. Soc. S. Aust. (in this volume).

Bloch, M. R., Farkas, L., and Litman, H. L., 1951. The Formation of "Salt Tables" in Natural and Artificial Solar Pans, Bull. Res. Council Israel 1: 36-39.

Bonython, C. W., 1955. Lake Eyre, South Australia- the Great Flooding of 1949-50. Roy. Geogr. Soc. A/asia, S. Aust. Branch, Adelaide. (a) The Geography of Lake Eyre and its Surroundings, 7-9; (b) The Filling and Drying-up, 27-36, (c) The Evaporation Rate, 37-56; (d) The Area, Volume and Salt Content, 63-68; (e) The Depression of Lake Eyre below Sea Level, 69-70.

Bonython, C. W., and King, D., 1955. The Occurrence of Native Sulphur at Lake Eyre. Trans. Roy. Soc. S. Aust. (in this volume).

Bonython, C. W., and Mason, B., 1953. The Filling and Drying of Lake Eyre. Geogr. Jour 119 (3): 321-330.

Fenner, C., 1952. Lake Eyre in Flood, 1950 – Mud, Salts, etc., Trans. Roy. Soc. S. Aust. 75: 5-8.

Fitzpatrick, A. S., and Strong, H. W., 1925. Investigation of Waters and Saline Materials from Lake Eyre and District (Central Australia), Proc. Roy. Soc. Vic. 37 (1): 98-103.

Goldschmidt, V. M., 1954. Geochemistry, Oxford, Clarendon Press.

Grabau, A. W., 1920. Principles of Salt Deposition, 1st Ed., New York, McGraw-Hill.

Jack, R. Lockhart, 1921. The Salt and Gypsum Resources of South Australia, Bull. No. 8, Geol. Surv. S. Aust.

King, D., 1955. The Quaternary Stratigraphic Record at Lake Eyre North and the Evolution of Existing Topographic Forms, Trans. Roy. Soc. S. Aust. (in this volume).

Madigan, C. T., 1930. Lake Eyre, South Australia, Geogr. Jour. 76: 215-240.

Madigan, C. T., 1946. Crossing the Dead Heart—Melbourne, Georgian House.

Penman, H. L., 1955. Lake Eyre, South Australia – The Great Flooding of 1949-50, Roy. Geogr. Soc. A/asia, S. Aust. Branch, Adelaide – Evaporation from Lake Eyre, 57-61

APPENDIX III.

Analyses of Lake Bed Sediments.

Sample No.	(40)	(41)		(42)	(43)	(44)	(45)		(46)
Bore No.	24/54	93/54							
Depth below salt crust surface	1′ 0″– 1′ 6″	1′ 2″– 1′ 11″		2′ 10″– 3′ 0″	3′ 3″– 3′ 4″	3′ 9″– 4′ 0″	5′ 6″– 5′ 9″		7′ 0″
Radicles —% by wt.									
Na	4·84	3·79		21·69	7·35	30·70	4·00		
Ca	20·08	21·45		7·34	12·52	3·81	21·25		22·92
Mg	0·59	0·55		0·06	0·63	0·31	0·66		0·57
Cl	6·85	5·74		32·86	10·24	47·20	6·17		
SO_4	48·94	51·05		18·52	30·45	10·30	51·97		56·72
CO_3	1·38	1·65		—	2·17	—	1·11		—
Assumed composition % by wt.	(i)	(i)	(ii)	(i)	(i)	(ii)	(i)	(ii)	(ii)
$CaCO_3$	—	2·75	1·7	—	3·61	—	—	—	—
$MgCO_3$	2·02	—	—	—	—	—	1·35	0·9	—
$CaSO_4$	68·10	69·05	54·7*	24·86	37·58	16·36*	72·10	59·5*	98·5*
NaCl	11·30	9·46	5·9	54·10	16·90	77·90	10·18	6·7	—
$MgSO_4$	—	2·73	1·7	—	3·12	1·53	1·35	0·9	2·0
Na_2SO_4	1·21	0·23	0·1	1·12	2·16	—	—	—	—
Free water			28·5	—	—	3·10	—	26·0	—
Insolubles	10·17	11·91	7·4	18·63	—	1·21	9·23	6·0	0·60

(i) Composition of oven-dried material. (ii) Composition expressed on wet basis.

* Expressed as $CaSO_4.2H_2O$

Sample No. (47)	Bore 93/54, Depth 12 ft.
SiO_2	6·56 % by wt.
Al_2O_3	1·71
Fe_2O_3	0·63
MgO	15·07
CaO	23·94
Na_2O	3·73
K_2O	0·28
Total water	9·40
CO_2	33·76
SO_3	2·16
Cl	4·09
S	0·20
	101·53
Less O equiv. Cl	0·92
	100·61

Notes on samples.

(40), (41), (43) and (45). Gypsum "slush". }
(42) Very hard stratum. } Analysed by S. M. Shephard.
(44) Lumps embedded in gypsum "slush". }
(46) Crystals embedded in gypsum "slush". }
(47) Dolomite bed. Analysed by T. R. Frost.

APPENDIX IV.

Analyses of Surface Waters in Queensland.

Stream	Barcoo			Thompson					
Place	Isisford			Longreach					
Date	17/3/33	24/2/39	21/12/49	15/12/36	15/2/37	15/5/37	24/7/37	21/1/43	30/10/50
Composition—mgm. per litre (p.p.m.)									
$CaSO_4$		17	17	60	66	36	27	21	64
$MgSO_4$	-		—	—	—			·	16
Na_2SO_4	—		—	—				—	-
$CaCO_3$	83	54	51	69	69	77	91	66	-
$MgCO_3$		—	—	-			—	—	
Na_2CO_3	—	—	26	—	—		—	34	54
NaCl	19	14	14	47	47	19	24	14	47
Total solids	435	191	149	331	300	257	166	166	371
pH	—	-	9·8	7·2	8·0	7·4	7·2	9·4	6·8

Stream	Thompson		Cooper		Diamantina	Wilson	Burke		Cooper*
Place	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)
Date	5/11/46	5/11/46	30/9/38	2/2/45	?	2/2/46	5/9/12	2/2/48	12/11/55
Composition—mgm. per litre (p.p.m.)									
$CaSO_4$	107	107	24	41	9	20		7	—
$MgSO_4$		—	—	—	—	17	—	—	—
Na_2SO_4	—	—	—	—	—		—	—	43
$CaCO_3$	10	10	80	10	57	—	120	40	52
$MgCO_3$	—	—	—	17	-	—	41	17	21
Na_2CO_3	6	31	—	50	—	34	—	10	51
NaCl	23	23	14	23	11	23	9	10	165
Total solids	171	200	129	274	314	183	394	131	371
pH	7·5	7·5		—	—	—	—	—	8·2

Key to places.

(i) Jundah.
(ii) Stonehenge.
(iii) Windorah.
(iv) Nappamerrie.
(v) Conn Hole, Elderslie.
(vi) Nockaburrawarra.
(vii) Near Duchess.
(viii) Boulia.
(ix) Birdsville Track Crossing, South Australia.

Sources of analytical data—Irrigation and Water Supply Commission and Railway Department, Queensland, and Engineering and Water Supply Department, South Australia.

* Sampled by South Australian Museum Expedition.

APPENDIX I.

Solid Salt Analyses.

Sample No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Collected by				a					a	a	a	a	a	a	b	b
Date				1/9/54					21/5/53		28/8/54	2/9/54	2/9/54	27/8/54	?/12/29	
Analyst				c					c	c	c	c	c	c	d	d
Level below surface	0-1″	1½-3″	3-4½″	5″	5-6″	7-8″	8-9″	9½-11″	0-2½″	2½-5½″	surf.	surf.	surf.	surf.	0-8″	surf.
Radicles—% by wt.																
Na^+	38·90	38·36	38·10	37·31	39·09	38·51	37·53	38·41	35·65	36·30	38·60	34·60	38·15	36·80	37·56†	37·60†
Ca^{++}	0·12	0·32	0·53	0·91	0·11	0·21	0·64	0·42	0·22	0·40	0·05	1·24	0·28	0·28	0·95	0·90
Mg^{++}	0·05	0·02	0·01	0·05	0·04	0·03	0·07	0·02	0·01	0·01	0·07	0·12	0·11	0·38	0·05	0·03
Cl^-	60·10	59·10	58·70	57·15	60·00	59·05	56·75	59·05	54·85	55·95	59·40	52·85	58·80	56·70	58·15	58·45
SO_4^{--}	0·46	0·90	1·37	2·61	0·43	0·66	3·31	1·51	0·59	0·98	0·43	3·61	1·09	2·15	1·81	1·64
CO_3^{--}	0·02	0·06	0·04	0·13	0·12	0·05	0·02	0·02	—	—	—	0·27	—	—	—	—
Assumed composition—% by wt.																
NaCl	99·00	97·40	96·75	94·25	99·00	97·50	93·55	97·25	90·50	92·25	98·00	87·10	96·95	93·50	95·28†	95·64†
$MgCl_2$		—	—	—	—	—	—	—	—	0·01	—	—	0·01	—	0·20	0·12
$MgSO_4$	0·25	0·11	0·05	0·26	0·22	0·14	0·34	0·12	0·07	0·04	0·40	0·48	0·51	1·86	—	—
$CaCO_3$	0·04	0·10	0·06	0·22	0·20	0·08	0·04	0·04	—	—		0·45	—	—	0·44‡	0·50‡
$CaSO_4.2H_2O$	0·46	1·22	2·18	3·55	0·11	0·76	2·69	1·75	0·96	1·70	0·19	4·55	1·22	1·21	3·29	2·99
Na_2SO_4	—	0·18	0·16	0·64	0·29	0·18	2·27	0·66	—	—	—	1·07	—	—	—	—
Free water	1·18	1·03	0·70	1·22	0·26	1·36	1·09	0·71	8·03	5·88	1·30	2·00	1·27	3·30	0·82	0·63
Insolubles	0·12	0·04	0·03	0·21	0·11	0·01	0·02	0·04	0·10	0·01	0·09	4·31	0·14	0·09	0·84	0·86

Sample No.	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
Source	Bore 4/54		Bore 24/54		Bore 50/54			
Collected by	a		a		a			
Date	25/8/54		26/8/54		27/8/54			
Analyst	c		c		c			
Level below surface	1-3″	4-6″	3-4″	6-8″	0-2″	2-4″	4-6″	6-8″
Ca^{++} % by wt.	0·47	0·40	0·42	0·20	0·21	0·31	0·66	0·43
$CaSO_4.2H_2O$	2·09	1·81	1·80	0·84	0·90	1·31	2·84	1·86
Free water	6·18	11·11	5·55	2·90	6·63	10·86	12·69	14·29

a Collected by C. W. Bonython.
b Collected by C. T. Madigan.
c Analysed by S. M. Shephard.
d Analysed by W. S. Chapman.
* Includes K^+.
† Includes KCl.
‡ As $CaCl_2$.

Details of samples

(1)-(8). Sampled subsequently from block of salt lifted near Bore 93/54.
(9) & (10). Salt crust beneath 8 in. brine between Prescott Pt. and Kunoth Shoal.
(11). Stranded white numulitic drift salt, between Flags 32 and 33/54.
(12). Buckled crust ¼ mi. west of Prescott Pt.
(13). Efflorescent salt from buckled thin crust near Prescott Pt.
(14). Efflorescent salt from drift "island" near Flag 37/54.
(15). "Hole 2", 6 mi. from shore (see Madigan 1930).
(16). Salt crust sample 1 mi. north-east of Shelly Is. (see Madigan 1930).
(17)-(24). Solid crust sampled to determine gypsum content.

APPENDIX II.

Brine Analyses

Sample No.	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)	(37)	(38)	(39)
Collected by	e	a	a	a	a	a	a	f	a	a	a	a	b	b	g
Date	26/10/50	11/2/51	24/5/51	13/12/51	16/5/53	16/5/53	19/5/53	15/5/53	25/8/54	26/8/54	27/8/54	31/8/54	Dec./29	Dec./29	Aug./22
Analyst	h	c	j	c	c	c	c	c	c	c	c	c	d	d	k
Density—gm./ml. at 20°C.	—	1·0497	1·0785	1·1667	1·207	1·205	1·122	1·184	1·211	1·215	1·214	1·215	—	—	1·0660
Radicles— grams per litre															
Na^+	14·88	27·80	43·78	92·20	122·1	122·8	68·8	108·2	123·6	—	—	118·3	115·2	110·8	32·85
K^+	—	—	0·01		0·27	0·13	0·13	0·03	—	—	—	1·9	1·67	0·56	0·37
Ca^{++}	0·40	0·51	0·91	1·61	0·90	1·07	1·77	0·96	0·51	—	—	0·28	0·64	1·01	1·76
Mg^{++}	0·15	0·27	0·30	0·82	2·24	1·76	1·03	1·52	3·40	5·6	6·3	6·56	7·67	2·39	0·37
Cl^-	23·17	43·20	67 96	142·30	191·2	191·7	107·5	167·3	192·5	—	—	190·5	189·0	173·4	51·55
Br^-	—	—	0·01	—	—	—	—	—	—	—	—	—	0·11	0·04	0·17
SO_4^{--}	1·19	1·70	2·94	6·48	7·2	6·2	6·4	8·4	11·96	—	—	17·9	18·0	8·9	5·64
CO_3^{--}	0·06	—	0·04	—	0·06	0·05	0·07	0·03	—	—	—	—	0·19	0·06	0·14
Assumed composition— grams per litre															
NaCl	37·83	70·60	111·45	234·0	310·0	311·9	174·6	275·5	314·0	—	—	300·7	292·7	281·5	85·0
KCl	—	—	0·02	—	0·52	0·25	0·25	0·06	—	—	—	3·6	3·2	1·06	0·71
NaBr	—	—	0·01	—	—	—	—	—	—	—	—	—	0·14	0·05	0·22
Na_2SO_4	—	—	—	—	—	—	—	0·22	—	—	—	—	—	0·06	0·26
$MgCl_2$	0·28	0·57	0·37	0·64	3·80	3·69	1·77	—	2·6	—	—	8·6	13·4	2·83	—
$MgSO_4$	0·41	0·60	1·04	3·26	6·43	4·67	2·87	7·53	13·5	—	—	21·6	21·1	8·23	1·85
$CaCO_3$	0·09	—	0·07	—	0·11	0·09	0·12	0·06	—	—	—	—	0·32	0·10	0·23
$CaSO_4$	1·22	1·73	3·00	5·49	2·91	3·51	5·83	3·18	1·72	—	—	0·94	1·74	3·31	5·65

a Collected by C. W. Bonython.
b Collected by C. T. Madigan.
e Collected by E. A. Brooks.
f Collected by D. King.
g Collected by A. S. Fitzpatrick and H. W. Strong.
c Analysed by S. M. Shephard.
d Analysed by W. S. Chapman.
h Analysed by T. W. Dalwood.
j Analysed by T. R. Frost.
k Analysed by A. S. Fitzpatrick and H. W. Strong.

Details of Samples

(25). Lake water from centre of Madigan Gulf (see Fenner 1952).
(26) and (27) Lake water from Level Post Bay.
(28) Lake water from west of Sulphur Peninsula.
(29) Lake water from north-east extremity of Kunoth Shoal.
(30) Lake water from between Prescott Pt. and Kunoth Shoal.
(31) Lake water from off Artemia Pt.
(32) Brine from bore in lake bed sediments at Prescott Pt., 1953.
(33) Ground brine in salt crust—Bore 4/54.
(34) Ground brine in salt crust—Bore 24/54.
(35) Ground brine in salt crust—Bore 50/54.
(36) Ground brine in salt crust—Bore 93/54.
(37) Ground brine in salt crust—"Lake Hole 4" (see Madigan 1930).
(38) Brine from bore in lake bed sediments at Prescott Pt., 1929—"Bore 3" (see Madigan 1930).
(39) Water from Lake Eyre South, 1922. "Sample No. 2", from water 3 in. deep, 200 yd. from shore (see Fitzpatrick and Strong 1925).

Fig. a.—Traces of Madigan's car tracks near Prescott Point, May, 1953.

Fig. b.—Lake vehicle on Kunoth Shoal, 1954. "Crocodile skin" salt crust.

Fig. a.—Incipient polygonal cracking of damp lake bed near Prescott Point, 1953.

Fig. b.—Depressed patches in bed near Pittosporum Head, 1954.
(Cyclometer wheel gives scale.)

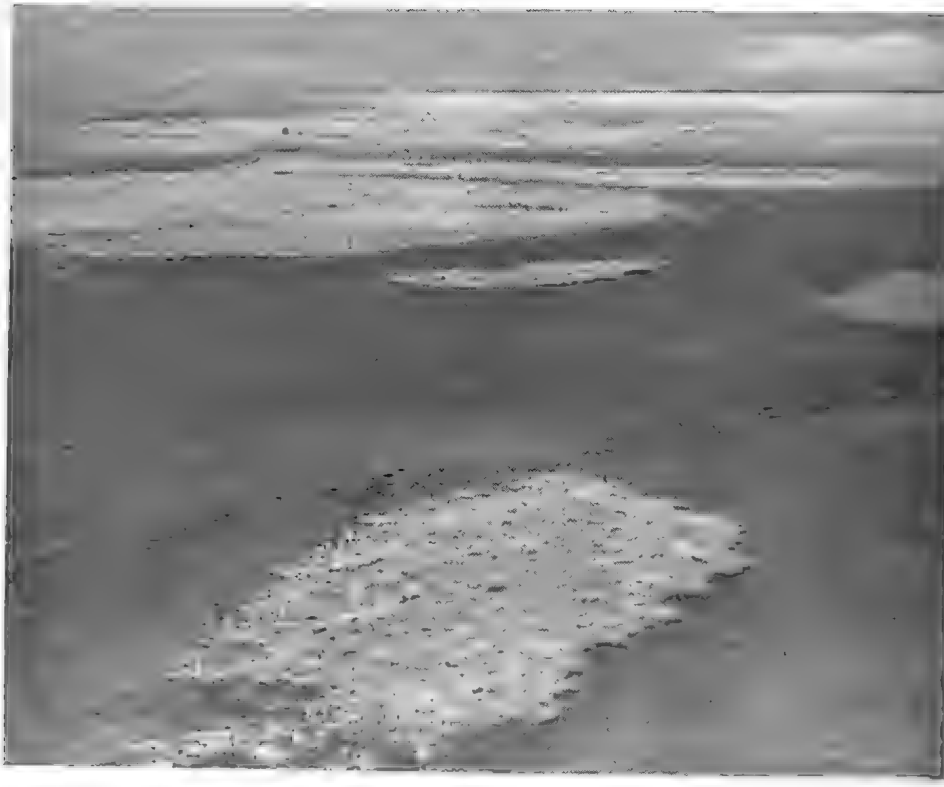


Fig. a.—"Ice-floe" salt surrounded by shallow water, May, 1953.

Fig. b.—"Waterlily" salt on Kunoth Shoal, May, 1953.

Fig. a.—Bank of "numulitic" drift salt, May, 1953.

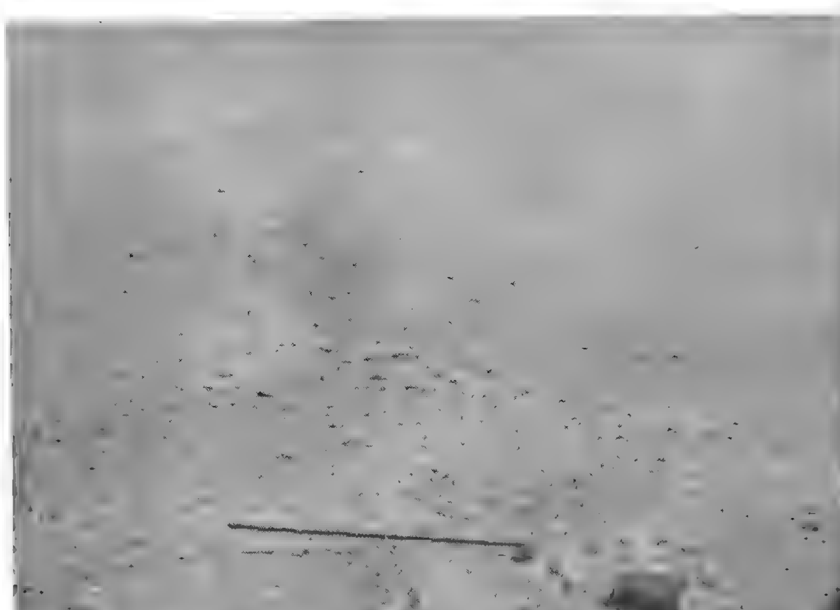


Fig. b.—Serpentine bank of "numulitic" drift salt, August, 1954.

Fig. a.—Rusty-pink drift salt "island" near Flag 37, August, 1954.

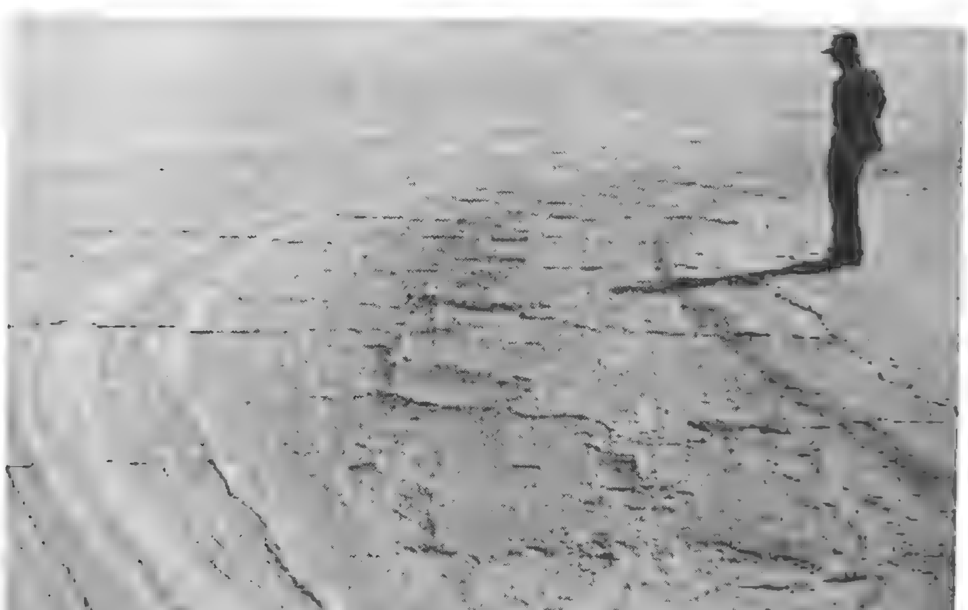


Fig. b.—Circular drift salt "island" near north-eastern shore of Madigan Gulf, August, 1954.

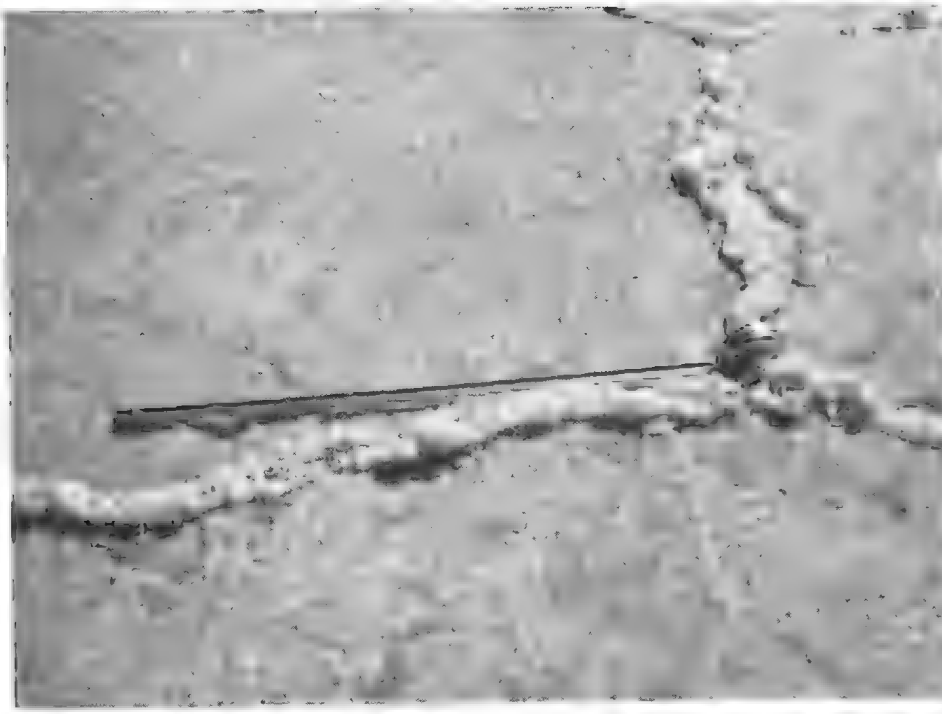


Fig. 1.—Efflorescent salt bulging from cracks in crust. (18-in. of tape measure gives scale.)

Fig. b.—"Ice pudding salt" showing embedded roly-poly bush. (18-in. of tape measure gives scale.)

Buckling developed in thin salt crust near Pittosporum Head, August, 1954.

Fig. a.—Preparing to remove block of salt at Flag 93, September, 1954.

Fig. b.—Block of salt after lifting. (Scale given by 8-in. ruler.)

THE QUATERNARY STRATIGRAPHIC RECORD AT LAKE EYRE NORTH AND THE EVOLUTION OF EXISTING TOPOGRAPHIC FORMS

BY D. KING

Summary

Fossiliferous Quaternary lacustrine deposits of the Lake Eyre Basin are exposed in escarpments along the margin of Lake Eyre North, and were intersected in shallow boreholes in the area. These are described in detail and their distribution shown on the geological maps.

The elevation of these earlier lake deposits above the present lake level, and their presence beneath a veneer of drift sand in the longitudinal ridges bordering the lake, have led to the conclusion that lake and dune formation are dual effects of wind erosion following desiccation in Early Recent times. Evidence is presented that a channelling effect of the wind played a major role in initiating dune development.

THE QUATERNARY STRATIGRAPHIC RECORD AT LAKE EYRE NORTH AND THE EVOLUTION OF EXISTING TOPOGRAPHIC FORMS

By D. King*

[Read 9 June 1955]

SUMMARY

Fossiliferous Quaternary lacustrine deposits of the Lake Eyre Basin are exposed in escarpments along the margin of Lake Eyre North, and were intersected in shallow boreholes in the area. These are described in detail and their distribution shown on the geological maps.

The elevation of these earlier lake deposits above the present lake level, and their presence beneath a veneer of drift sand in the longitudinal ridges bordering the lake, have led to the conclusion that lake and dune formation are dual effects of wind erosion following desiccation in Early Recent times. Evidence is presented that a channelling effect of the wind played a major role in initiating dune development.

I. INTRODUCTION

The subject matter of this paper is largely based upon observations by the writer while taking part in a scientific expedition to Lake Eyre North organized and led by Mr. C. W. Bonython in May, 1953. The operational base for this expedition was located on the south-eastern shore of Lake Eyre North near the channel connection to Lake Eyre South, at a distance of some 25 miles by ill-defined track north-west of Muloorina Station homestead.

An area of approximately 800 square miles — partly occupied by featureless lake bed — was embraced by the detailed survey, using R.A.A.F. air photographs as base maps. An interesting succession of Quaternary sediments was discovered in cliffs at the lake margins, and was encountered in a series of bores sunk with a post-hole auger at a number of places in the lake bed. The investigation has revealed several significant facts relating to sand dune development which were not formerly appreciated, all of which substantiate earlier work of the late Dr. C. T. Madigan.

A subsequent study of air photographs of the whole Lake Eyre region provided additional physiographic material which is also incorporated in this contribution.

Some new place names used in the text were proposed by Mr. Bonython and approved by the Lands Department Nomenclature Committee (Report of the Lake Eyre Committee, 1955, p. 7).

The writer acknowledges the co-operation and assistance of Mr. Bonython in the field, and the use of survey measurements by a member of his party (Mr. W. Fenner). He is indebted to the Director of Mines of South Australia for the opportunity to accompany the expedition and for arranging preparation of the maps for publication. Meteorological data was kindly made available by Mr. B. Mason, of the South Australian Weather Bureau.

II. REGIONAL PHYSIOGRAPHIC SETTING

Lake Eyre is the largest of numerous salinas which are distributed throughout the semi-desert areas of South Australia. Lake Eyre North has a total coverage of some 3,100 square miles, and is connected by a narrow water-course known as Goyder Channel to the smaller Lake Eyre South. The lakes are bounded on the east and north by an extensive dune-covered plain comprising the southern portion of the Simpson Desert (Madigan, 1938, p. 504). Along the western margin is a highly dissected tableland, and bedrock hills of the

* Geologist, Geological Survey of South Australia.

Peake-Denison Ranges, and to the south and south-west are gibber plains with scattered dune ridges bordering the Northern Flinders and Willouran Ranges.

Lake Eyre North is approximately 25 feet below sea level (L.W.O.S.T. Port Adelaide) (Bonython, 1955) and the general elevation of large areas of the

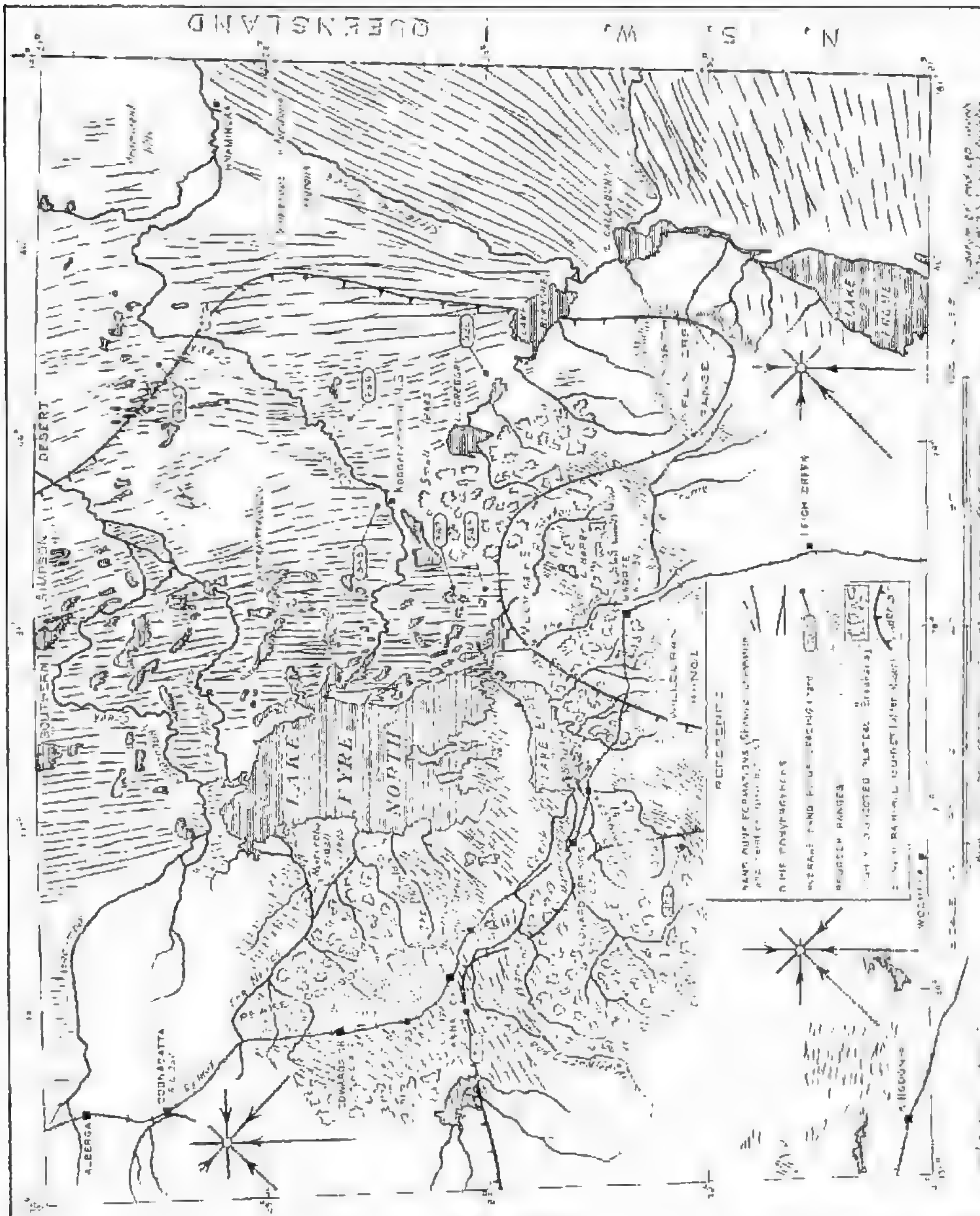


Fig. 1.—Map of north-eastern South Australia showing the physiographic setting of Lake Eyre.

adjoining plains is only a few feet higher than lake level. The lakes are consequently the focal point of drainage from a vast area of the interior, particularly from the north where the catchment includes higher rainfall areas in Central Australia and Queensland.

The main water-courses of the drainage system entering Lake Eyre are shown on Fig. 1. In normal years, any floodwaters from the north are dispersed and spent in smaller lagoons and deltas before actually reaching the lake, but in exceptional seasons such as experienced in 1949-50, Lake Eyre North may be completely flooded from these sources.

III. QUATERNARY STRATIGRAPHIC RECORD

The Lake Eyre region lies within the southern portion of the Great Artesian Basin. The broader geological features of Mesozoic and Tertiary rocks underlying the basin are described in earlier reports (Jack, 1915; Ward, 1946; Whittle and Chebotarev, 1952), and are chiefly based upon data from widely spaced boreholes sunk for water supply and petroleum exploration.

The area covered in detail during the present field survey comprises the south-eastern portion of the Lake Eyre Basin, where the Mesozoic and Tertiary rocks are covered by an appreciable thickness of Pleistocene and Recent lacustrine deposits.

The Quaternary sediments are now partly exposed in escarpments at the margin of Lake Eyre North due to subsequent desiccation and erosion, and were intersected in shallow boreholes sunk into the lake bed. The whole of the succession found in the area is fossiliferous, but the fauna present are a fresh to brackish-water association which cannot be relied upon for accurate age determinations. The lowest bed mapped is a gently folded dolomitic mudstone containing molluscan casts, and is regarded as Pleistocene in age. Overlying the dolomites unconformably are horizontally bedded gypseous clays containing ostracodes and oogonia of *Chara* and some native sulphur concretions, and capped by a deposit consisting almost entirely of shell remains and gypsum.

The Quaternary geology of the area as compiled from cliff exposures and borehole samples* is shown on the accompanying Fig. 2, and the following are descriptions of the main members of the sedimentary succession in ascending order:

PLEISTOCENE(?)

Dolomitic mudstones:

This member is a hard dolomitic mudstone measuring at least 20 feet in thickness and containing casts of shells (*Coxiella gilesi*) and thin lenticular laminae of green clay† and gypsum. It outcrops along the entire length of Hunt Peninsula at the southern end of Lake Eyre North, and farther to the east dips below the lake surface at an angle of about 5 deg. to the north-east. Samples of the dolomitic bed from three localities were chemically analysed by the Mines Department (under the direction of T. B. Frost) with the following results:

	Sample No. 1 Loc. C. cliffs per cent.	Sample No. 2 Loc. H. cliffs per cent.	Sample No. 3 Borehole, Madigan Gulf per cent.
Calcium oxide, CaO	24·14	29·54	23·94
Magnesium oxide, MgO	16·97	19·34	15·07
Acid insolubles	2·50	4·68	

* The results of boring are shown diagrammatically in the cross-sections accompanying Figs. 2 and 3, and detailed logs are recorded in an official report filed with the Department of Mines.

† The clay mineral palygorskite has been identified in such clays from a borehole at Loc. C by L. Rogers, C.S.I.R.O., Division of Soils.

The result of a complete chemical analysis of Sample No. 3, together with exact details of its location, is contained in a paper by C. W. Bonython (1955 (a)), which is published in this volume.

The dolomite is fine-grained, and the uppermost layers are indurated by silicification (Plate 2, Fig. 1). Intraformational pellet structures and slump folding are widely developed and indicate their deposition in a shallow water environment. The dolomitic matrix of these sediments is probably a chemical precipitate resulting from periodic changes in salinity, in the same way as dolomite is forming at present in some other South Australian lagoons (Forbes, 1955).

EARLY RECENT(?)

(1) *Vari-coloured gypseous clays*

The dolomitic rocks are overlain unconformably by vari-coloured plastic clays passing upwards into pale green and brown sandy clays which attain a maximum observed thickness of up to 25 feet. The clays are exposed a few feet above lake level along the shores of Sulphur Peninsula, where they contain concretions of sulphur and gypsum (Bonython & King, 1955 (b)) and were penetrated by borings over a wide area in the south-eastern portion of Lake Eyre North. Samples from boreholes were examined by N. H. Ludbrook (1953, 1955) and found to contain numerous remains of the fresh-water plant *Chara*, ostracodes, and some foraminifera.

The unconformity at the base of the clays may be seen in the cliffs near Loc. D., where it is recorded by an eroded old surface of the dolomite, and elsewhere boreholes showed the presence of a thin limestone and quartz gravel bed resting upon the dolomite (Fig. 4).

The clay beds vary in colour both laterally and in depth due probably to variations in the state of oxidation of the iron content, but are essentially similar in composition and physical properties over their entire width. The main ingredient is extremely finely divided clay matter, shown by X-ray analysis to be largely amorphous and indeterminable. Other important constituents are evenly distributed rounded quartz grains, and thin partings of natural whiting. Gypsum crystals occur sporadically throughout the clays and in the lower horizons there are interstratified thin beds of crystalline gypsum. Samples taken from the lake bed develop an efflorescent coating of salt on drying, as previously described by Fenner (1952).

EARLY RECENT(?)

(2) *Gypseous shell beds*

The uppermost beds consist mainly of fragile shell remains (*Coxiella gilesi*) loosely embedded in fine siliceous and gypseous sand and clay, and interstratified with layers of gypsum crystals (Plate 1). In most places along the shoreline these beds have been removed by wind erosion and are only locally preserved where protected by drift sand deposits.

A complete section of the shell beds may be observed in the low shoreline cliffs adjacent to Shelly Island (Loc. M) where they are 4½ feet thick, and the uppermost bed is elevated approximately 36 feet above the level of the margin of Lake Eyre North. A layer of massive crystalline gypsum one foot thick, featured by strongly ripple-marked partings, underlies the shell remains. A detailed description of the section exposed at this locality is shown in Table 1.

Other outcrops of the shell beds are known on the eastern side of Sulphur Peninsula (Loc. S.E.), on the western side of Price Peninsula (Loc. A.), and in the upper levels of a small butte which rises prominently above the featureless limestone plain south-west of Shelly Island. All are elevated approximately 30 feet above the present lake surface.

Environment—Throughout this record the fossil evidence suggests predominantly brackish water conditions with periods of desiccation which gave rise to deposition of crystalline gypsum beds (and salt), and the temporary extinction of fish and invertebrate fauna. The lithology of the sediments is consistent with deposition in a permanently inundated, but gradually receding, inland lake basin — "Lake Dieri" (Fenner, 1952). No evidence was found to support earlier generalizations that there may have been a connection between Lake Torrens (approx. 100 feet above sea level) and the head of Spencer Gulf coeval with varying sea levels of the Pleistocene (David, 1932).

TABLE 1

DETAILED DESCRIPTION OF SUB-RECENT GYPSEOUS SHELL BEDS

Location M

LAKE EYRE NORTH

Situation—Peninsula on southern shore of Lake Eyre adjacent to Shelly Island. Approx. 6 miles W.S.W. of Sulphur Point.

A.R.L.* of top of section = 136.

Ft. In.	Ft. In.	
0 0	— 1 10	Shells (*Coxiella gilesi*) embedded in fine gypseous sand. Siliceous grit and limestone pebbles. Uppermost layer forms flat pavement, partly covered by drift sand.
1 10	— 1 11	Crystalline gypsum rosettes.
1 11	— 2 3	Shells (*Coxiella gilesi*) embedded in fine gypseous sand and siliceous grit with narrow clay partings. Clusters of gypsum crystals.
2 3	— 2 7	Pale grey clay with a few shells (*Coxiella gilesi*).
2 7	— 2 10	Shell bed (*Coxiella gilesi*) in fine gypseous matrix.
2 10	— 2 11	Pale grey clay.
2 11	— 3 1	Shells (*Coxiella gilesi*) and fish vertebrae in fine matrix of sandy clay.
3 1	— 3 4	Grey clay and fine sand. Clusters of shells (*Coxiella gilesi*) in places.
3 4	— 3 6	Very fine white siliceous sand.
3 6	— 4 0	Shells (*Coxiella gilesi*) embedded in very fine pale grey siliceous sand.
4 0	— 4 1	Grey clay with some gypsum.
4 1	— 4 2	Pale grey fine siliceous sand—odd shells (*Coxiella gilesi*).
4 2	— 4 3	Shell (*Coxiella gilesi*) fragments in light sand and rounded quartz grit.
4 3	— 4 4	Fine pale grey siliceous sand.
4 4	— 4 4½	Clay with gypsum.
4 4½	— 4 6	Fine pale grey siliceous sand with shell fragments (*Coxiella gilesi*) near top.
4 6	— 4 10	Grey clay and abundant gypsum.
4 10	— 6 6	Section covered by drift.
6 6	— 7 6	Bed of massive crystalline gypsum with ripple-marked surfaces.

* Arbitrary Reduced Level—see Bonython (1955 (a)).

The deposition of the shell beds marks the final desiccation of the Pleistocene—Early Recent(?) lake, which was followed by the introduction of dominantly erosive agencies which it will be shown were largely responsible for the sculpturing of existing topographic forms.

IV. THE SAND FORMATIONS

The sand ridge formations which are so strongly developed beyond the eastern and northern margins of Lake Eyre — within the southern limits of the Simpson Desert — have been described in considerable detail in a series of contributions by Madigan (1929-1946). The area embracing the north-eastern portion of the State has since been covered by R.A.A.F. air photography (1945 and 1948), which together with ground observations during the present investigation, has provided an opportunity for additional research on the sand formations over large areas lying beyond the limits of Madigan's surveys.

The distribution and orientation of the dune ridges over a wide area surrounding Lake Eyre are shown on the topographical map (Fig. 1). An analysis of present day wind records from weather stations at Oodnadatta, Leigh Creek and Woomera is also presented on this map.*

The dunes of the Lake Eyre region are consistently of the longitudinal (or seif) type, as described by Bagnold (1941, p. 189). East of Lake Eyre, the ridges are aligned meridionally and evidently retain this orientation for several hundred miles to the north (Madigan, 1946). South-west of Lake Eyre there is a gradational change in dune trend from a dominant east-north-east direction near the lake to approximately east-west in the area west of the Central Australian Railway. A similar but opposing swing from northerly to easterly is also a marked feature of the dune pattern in the Lake Frome Plains, to the south-east of Lake Eyre.

The sand dune belts and individual ridges have the following characteristics:

1. It may be generally stated that the degree of completeness to which the dune topography has developed increases gradually to the north-east. The dunes south-west of Lake Eyre, for example, are broad and ill-defined sand strips which are of approximately equal width to the intervening troughs (Plate 4, Fig. 1). Towards the Simpson Desert, the definition and dimensions of the ridges increases, and they stand out in bold relief from the considerably wider interdune corridors (Plate 4, Fig. 2).

2. An outstanding feature of the dune morphology is the widespread occurrence of dune convergences, despite the otherwise rigid parallelism of the formations. These are usually represented in ground plan by an assymetric and inverted Y, and in every case the point of convergence is directed in the north to east quadrant, depending on the dune trend in the particular area.

3. Individual ridges have been observed to exceed twenty miles in length (Lat. 29°00′S.; Long. 138°15′E.) and may be much longer in places. It is only rarely, however, that dunes persist for such distances without converging and becoming composite formations.

4. The lateral spacing of the dunes is variable, but systematic, and appears to increase in a direct proportion to the height of the formations. The average dune spacing at a number of arbitrarily selected localities throughout the region (as measured from air photographs) are recorded on the topographic map (Fig. 1). These figures indicate a range from 3 to 33 dunes to the mile, and a usual spacing of about one-quarter mile.

5. The height of the dunes in areas examined by the writer is of the order of 40 feet. Madigan (1946, p. 48) reports that some in the central Simpson Desert are about 100 feet high.

6. In cross-section, the ridges are slightly asymmetric, with the steepest side to the east or south — according to trend.

7. The main mass of the dunes, and the interdune valleys, are now fixed by a stunted psammophytic vegetation (Crocker, 1946, p. 249). However, in many cases the dune crests consist of "live" sand which is modelled into minor structures by wind storms without any appreciable drift. A particularly common result of recent wind activity are successions of small fulje-like hollows along the crest of the ridges, giving rise to a characteristic "ribbed" or "plaited" structure (Plate 3).

A series of boreholes sunk into the sand formations at the south-eastern margin of Lake Eyre North (Price Peninsula) indicates that the longitudinal ridges in this area are only superficially formed of drift sand. The main mass

* The wind roses have been especially prepared to include only summer afternoon winds of greater velocity than 10 m.p.h. Such conditions are considered to be most favourable for shifting sand.

of each ridge is composed of buried lacustrine deposits, including the Early Recent(?) shell beds and clayey sand horizons which were observed in some shoreline cliffs and are described in the preceding section. In the interdune corridors, the same beds have been removed by erosion and the surface soil is underlain by laminated clays of a lower stratigraphic level.

Details of the internal structure of the dunes as provided by boring are shown on the accompanying Fig. 3, on which surface levels and borehole logs are accurately recorded at an exaggerated vertical scale.

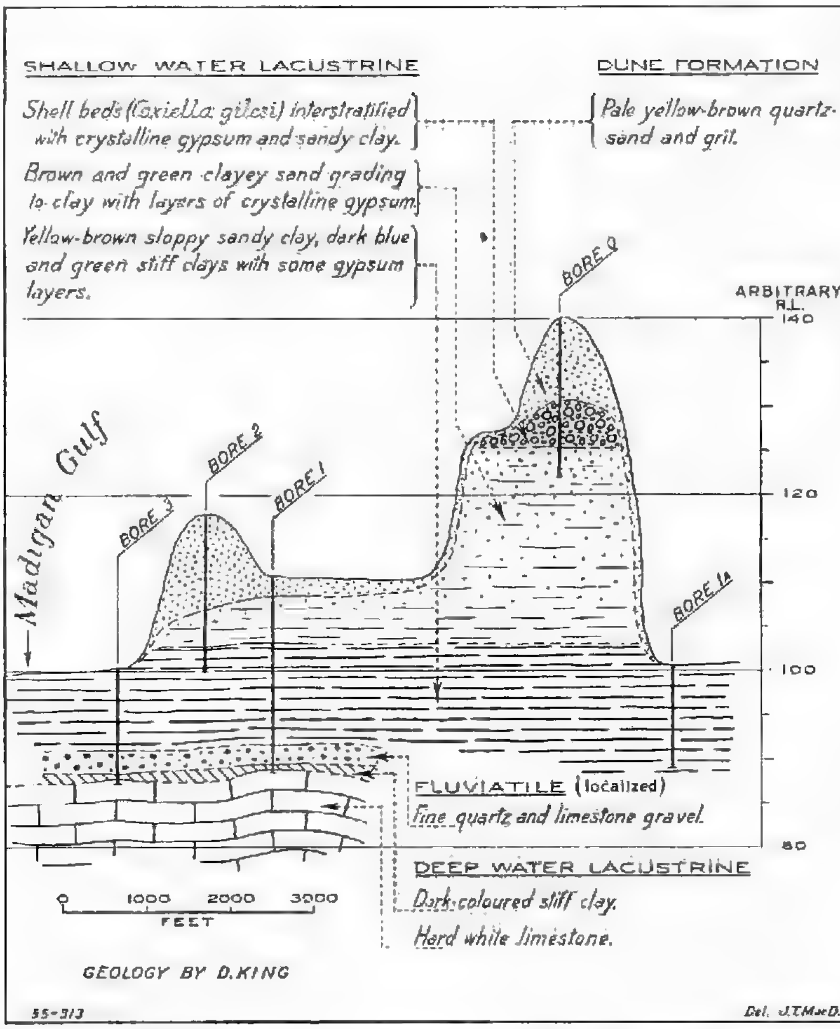


Fig. 3.—Diagrammatic geological section through sand ridges on S.-E. margin of Lake Eyre North.

The borehole at Position O is located on the crest of a prominent longitudinal dune at an elevation of 40 feet above the margin of Lake Eyre North (A.R.L. 100) and 30 to 40 feet above the interdune depressions on either side. In this borehole, aeolian sands were found to give way to gypseous shell beds at 9½ feet depth. At a depth of 15¾ feet, the bore penetrated grey sandy clays and sand, and bottomed in a bed of crystalline gypsum at 22 feet above present lake level.

Screen analyses were carried out on samples recovered from Borehole O with the following results:

Sample No.	Depth of Sample		Sizings B.S.S. (By weight)						
	From	To	+18	−18+30	−30+60	−60+100	−100+200	−200+300	−300
1	0′ 0″	0′ 0¼″	10·25	34·5	32·5	6·75	4·0	0·5	11·5
2	0′ 0¼″	8′ 0″	2·5	3·0	33·0	19·5	32·25	6·25	3·5
3	8′ 0″	9′ 6″	2·0	7·5	31·0	13·5	21·5	8·5	16·0
4	9′ 6″	13′ 6″	9·5	16·25	29·25	12·0	18·0	8·5	6·5

Sample No. 1 is representative of a noticeably coarser quartz sand which characteristically forms a thin surface layer on the dune ridges.

Samples Nos. 2 and 3 consist of well-sorted siliceous sand from the main mass of the aeolian deposits. Grain diameters mostly lie in the − 30 + 200 grade, between 0·25 and ·076 mm., and are comparable with samples taken from longitudinal dunes elsewhere in the region (Carroll, 1944).

Sample No. 4 comprises the sandy matrix of the underlying shelly lacustrine deposits. As might be expected in this case, the screen analysis indicates a much lesser degree of sorting than featured by the wind blown sands.

At a number of localities along the south-west shores of the lake the coastal dune sands have been observed to largely comprise seed gypsum and shell fragments. These gypseous dunes are well exposed along the western margin of Sulphur Peninsula (Fig. 2), where they were previously noted by Madigan (1930). The base of the dunes corresponds with the present level of the lake, indicating that they are a quite recent shoreline feature.

V. EVOLUTION OF THE TOPOGRAPHIC FORMS

Lake Eyre North is approximately 25 feet below L.W.O.S.T. Port Adelaide (Bonython, 1955 (a)) and would be expected to have silted up to a considerable depth under the prevailing conditions of endoreic drainage. However, this is not the case as shown by the following conclusions drawn from the evidence presented in the preceding pages:

1. The occurrence of undisturbed Early-Recent(?) sediments in shoreline cliffs at an elevation of 36 feet above the lake bed shows conclusively that the evolution of the lake as it is today has actually involved erosion and removal of at least a corresponding thickness of earlier lake deposits.

2. Boring in the desert-sand formations along the south east shore of the lake has revealed that an appreciable thickness of Early-Recent(?) lake deposits has been removed from interdune valleys and lagoonal depressions, but practically the whole succession of these sediments is preserved in longitudinal ridges upon which the dune formations are superimposed.

It is evident from these erosional features that lake and dune development have proceeded concurrently. The excavation of the lakes and interdune corridors to their present level has involved — at least in the case of Lake Eyre* — the removal of older Quaternary lacustrine sediments by deflation, and the sandy fractions of the transported material have accumulated beyond the lake shores as longitudinal sand strips forming a veneer upon the crests of a corrugated land surface.

* It is, however, not overlooked that the Lake Eyre Basin as a whole is probably due to regional subsidence.

The direction of general sand movement is reflected by the orientation of the dune ridges, and by the remarkably regular shape and shore features of the lakes throughout the region. These all show the effects of sand migration towards the north and north-east, as outlined hereunder:—

The origin of the dune ridges appears to be satisfactorily explained by Madigan (1946) as due to dominant winds and sand movement parallel to the dune length (southerlies to south-westerlies), and periodical gusty side winds (chiefly westerlies). This conclusion is supported by the coincidence of regional dune trends with present day prevailing winds (Fig. 1), and by evidence of the internal structure of the ridges which indicates that no lateral movement of the main body of the ridges near Lake Eyre has occurred at any stage.

Pastoralists along the Marree-Birdsville track have observed that the spread of present day drift is towards the north (Madigan, 1946), and the same feature is also indicated by the aerial photographs (Plate 3). This occurs despite the fact that many of the dust-storms which are a feature of the summer season throughout this part of the State are directed from the north and must at least modify the rate of sand migration.

Several stages in the evolution of the longitudinal dunes and related claypans (or "blow outs") appear to be represented by existing topographic forms in marginal lake areas.

The initial channelling action of the wind may be observed to be operating on a small scale at the northern and north-western margins of all the lagoons, where there is an indefinite passage from lake bed to a bare and fluted wind-swept surface. To the leeward of the wind-swept areas, the drift sand accumulates as small transverse ridges which are grouped longitudinally and pass gradationally at increasing distances from the lakes into the normal longitudinal dune (Fig. 4).

These observations add credence to Bagnold's theory that the longitudinal dunes are a transition from earlier formed transverse formations, and may account for the "saw-tooth" profile of the ridges as described by Madigan (1946).

Once channelling by the wind commenced, the scouring effect would become increasingly effective in the hollows, and the rate of growth of the sand veneer on the intermediate ridges could be expected to increase accordingly. Once formed, the ridges with the greater protection of drift apparently survived the continued erosive effect of the wind, whereas others were reduced to the level of the interdune valleys — thus accounting for the observed variation of spacing with dune height.*

The dune convergences appear to be a result of the gusty side winds and their variable asymmetric forms suggest that both westerlies and easterlies were operative. The cross-winds were evidently capable of locally deflecting the leeward ends of some ridges where the cover of drift was of a minimum thickness and the ridges were of smaller bulk (Madigan, 1946). They may other-

* Prof. R. A. Bagnold comments on these generalisations in a personal communication of 10th December, 1955, as follows: "I find it difficult to accept that all the dunes in this area are really sand-covered relics of former lake deposits. One would like confirmatory data similar to Fig. 3 from other sites scattered over a large area, or over a long strip in the dune direction. You don't appear to have found any site where the non-aeolian core was exposed through some chance change in the local wind regime. If this is so, there would seem to be a strong tendency for the blown sand to creep *upwards* over everything: but the impression given by Fig. 3 is for the sand coating to be of even thickness everywhere — which I don't understand because it pre-supposes the sand to know how thick it is. It is, of course, just possible that either vegetation or thermal conductivity might explain this.

The prevalence of the Y-dune formations you have pointed out seems to fit in with the wind roses you give. There are two prevalent wind directions (or one very broad, indefinite one) and the directions of the two long arrows correspond well with the two arms of the Y in most places."

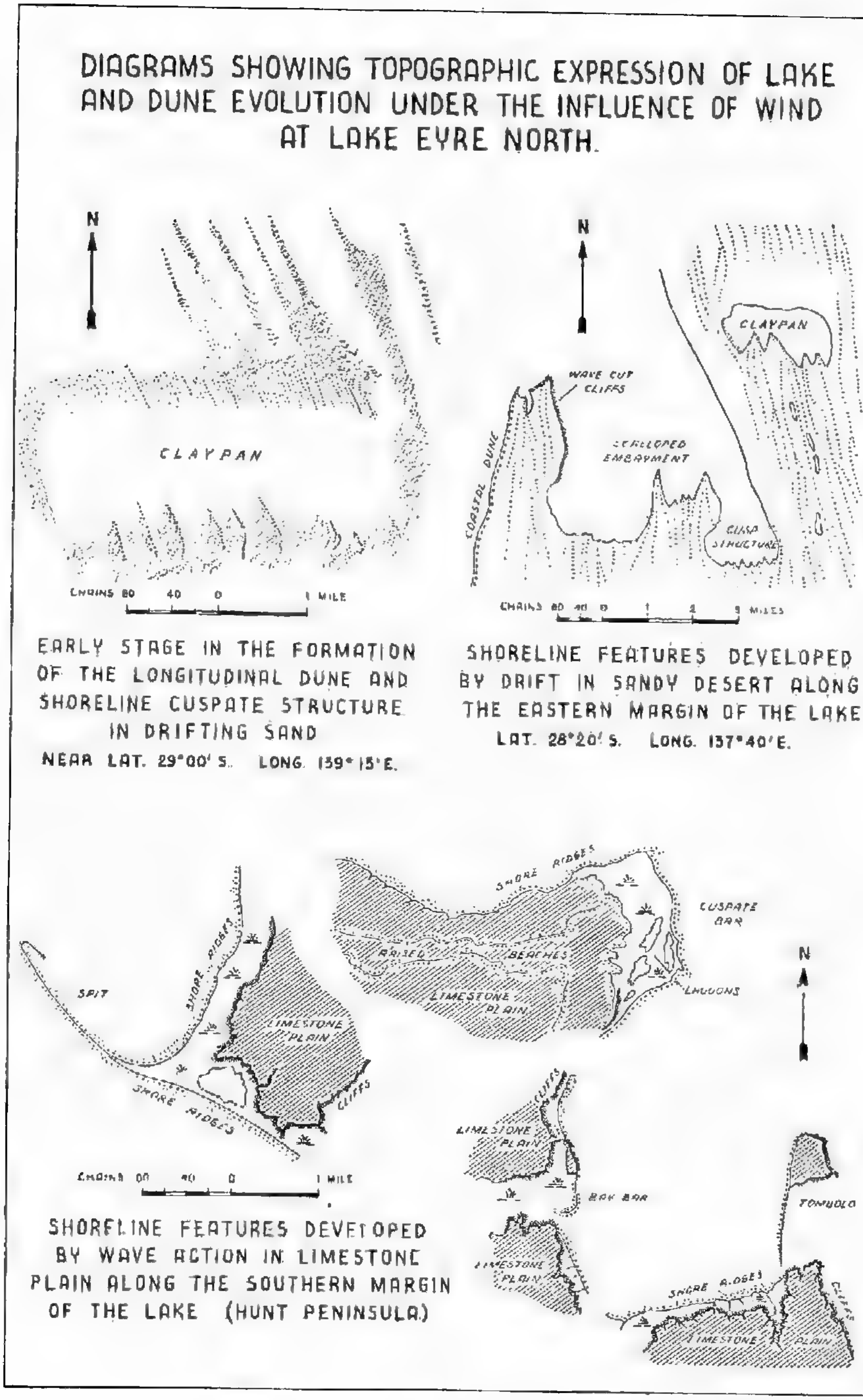

DIAGRAMS SHOWING TOPOGRAPHIC EXPRESSION OF LAKE AND DUNE EVOLUTION UNDER THE INFLUENCE OF WIND AT LAKE EYRE NORTH.
N
CLAYPAN
CHAINS 80 40 0 1 MILE
EARLY STAGE IN THE FORMATION OF THE LONGITUDINAL DUNE AND SHORELINE CUSPATE STRUCTURE IN DRIFTING SAND
NEAR LAT. 29°00′ S. LONG. 139° 15′ E.
N
CLAYPAN
WAVE CUT CLIFFS
SCALLOPED EMBAYMENT
COASTAL DUNE
CUSP STRUCTURE
CHAINS 80 40 0 1 2 3 MILES
SHORELINE FEATURES DEVELOPED BY DRIFT IN SANDY DESERT ALONG THE EASTERN MARGIN OF THE LAKE.
LAT. 28°20′ S. LONG. 137°40′ E.
SHORE RIDGES
CUSPATE BAR
RAISED BEACHES
LIMESTONE PLAIN
LAGOONS
N
SPIT
SHORE RIDGES
LIMESTONE PLAIN
SHORE RIDGES
CLIFFS
CHAINS 80 40 0 1 MILE
CLIFFS
LIMESTONE PLAIN
BAY BAR
TOMBOLO
LIMESTONE PLAIN
SHORE RIDGES
CLIFFS
LIMESTONE PLAIN
SHORELINE FEATURES DEVELOPED BY WAVE ACTION IN LIMESTONE PLAIN ALONG THE SOUTHERN MARGIN OF THE LAKE (HUNT PENINSULA)

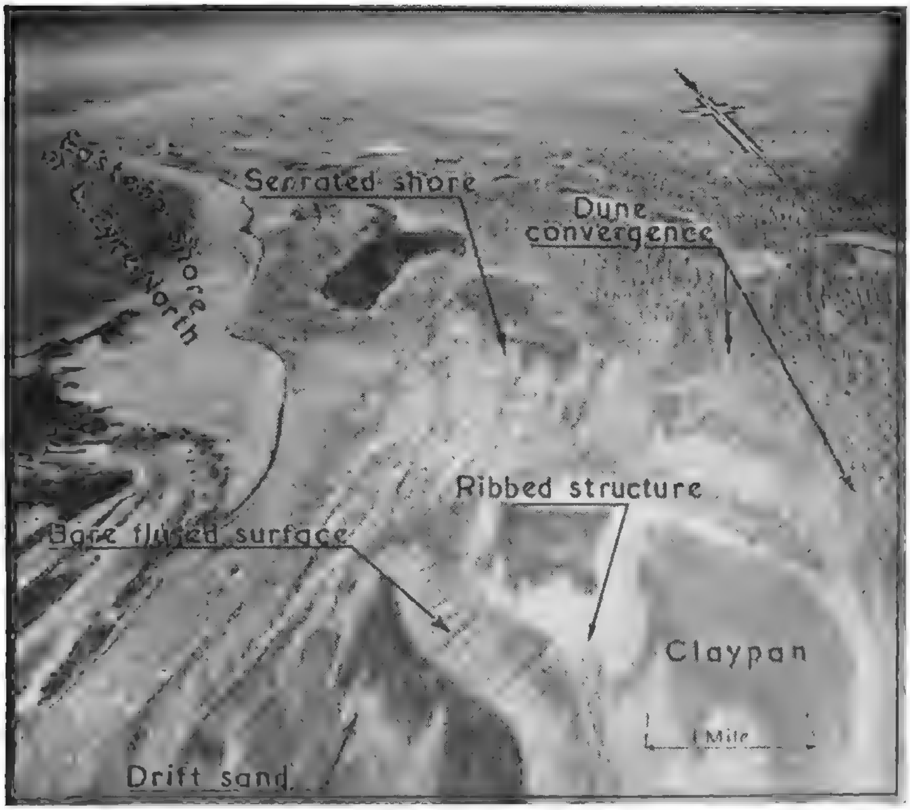
Fig. 4.

Fig. 1.—Shell beds (*Coxiella gilesi*) exposed at top of shoreline cliffs at the south-eastern margin of the lake (Loc. M.). These lacustrine sediments are elevated 36 feet above the general lake level.

Fig. 2.—Near view of shell beds (*Coxiella gilesi*) at top of cliff section in the same locality as above.

Fig. 1.—Dolomitic mudstones exposed in shoreline cliffs along the south-eastern margin of the lake (Loc. C). The cliffs have evidently formed by wave action during temporary inundations.

Fig. 2.—Shore of Lake Eyre North near Pittosporum Head, Hunt Peninsula, showing succession of beach ridges in background. The highest is about 30 feet above the lake margin.



Oblique aerial view of longitudinal sand dunes and claypans in the sandy desert east of Lake Eyre North, showing dune and shore features referred to in the text.—R.A.A.F. photo.

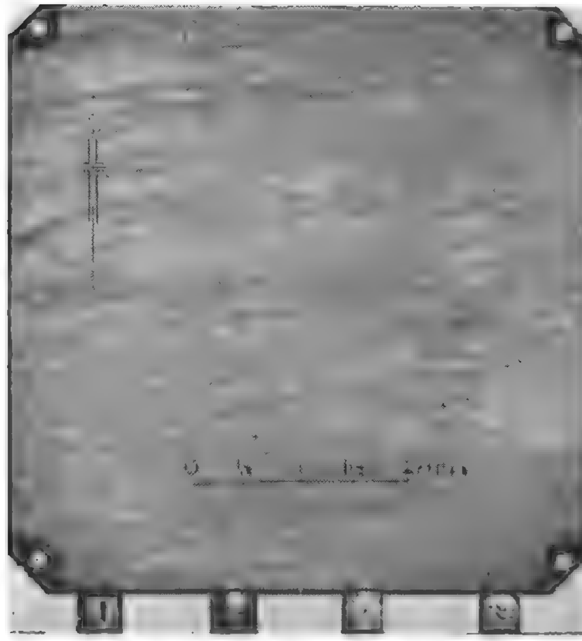


Fig. 1.—Broad east-west sand ridges and claypans typical of the dune topography west of Lake Eyre (Lat. 28° 55′ S; Long. 135° 45′ E.).

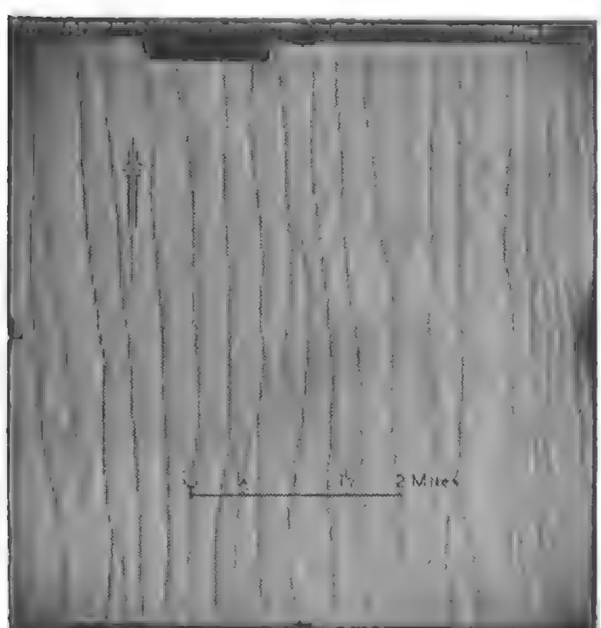


Fig. 2.—Strongly developed longitudinal dune ridges east of Clayton Lake. Lat. 29° 00′ S.; Long. 138° 15′ E.

R.A.A.F. Photos.

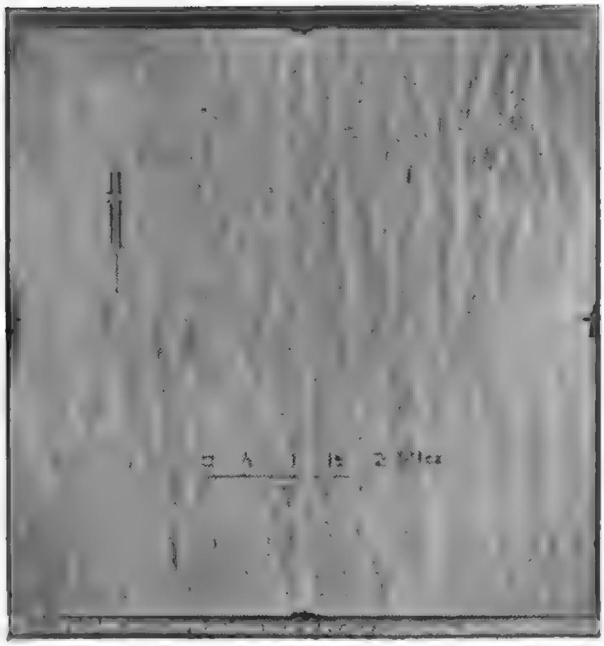


Fig. 1.—Converging system of longitudinal sand strips with interdune claypans near Kopperamanna. (Lat. 28° 28′ S.; Long. 138° 45′ E.)

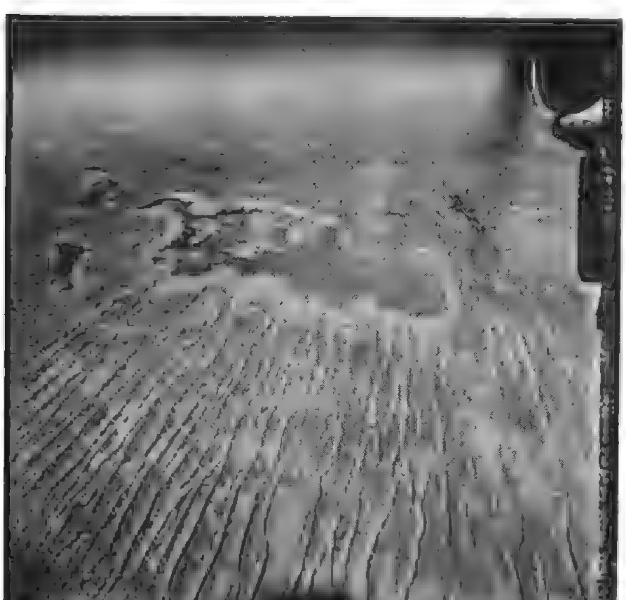


Fig. 2.—Oblique view of longitudinal sand ridges and claypans east of Lake Eyre North. Note typical serrated cusp-like form of southern margin of claypan. Foreground scale is approx. 1 inch to two miles. (Location of larger claypan is Lat. 28° 55′ S.; Long. 138° 00′ E.)

R.A.A.F. Photos

wise reflect the termination of the wind-eroded channels which preceded dune development.

Although present-day climatic conditions are probably favourable for the continuation of this process, the dune ridges and level of the lake appear to have become stabilized due to the decreased susceptibility of underlying clays and dolomites now forming the lake beds to this form of erosion.

Periodic floodings of Lake Eyre North have continued until the present and have resulted in the local development of marine-type shore features. These are well preserved along the southern margins of the lake where the foreshore has a rugged and indented outline defined for the greater part by steep cliffs up to 40 feet high. Beach ridges composed of limestone shingle form a variety of bars and spits marking the level of the last flooding (1949-50), and others representing earlier floodings are stranded at various heights and with various orientations unrelated to the present foreshore up to a maximum of about 30 feet above the lake bed (Fig. 2 and Plate 2, Fig. 2).

The effects of wave action are not represented in the numerous isolated embayments and lagoons which occur to the east of Lake Eyre and receive only local rainfall. Instead, the corresponding southern shores show a remarkably consistent and well-developed serrated or cusp-like structure produced by encroachment of sand from the south (Fig. 4).

REFERENCES

BAGNOLD, R. A., 1941. The Physics of Blown Sand and Desert Dunes. Methuen & Co. Ltd., London.

BONYTHON, C. W., 1955 (a). The Salt of Lake Eyre—Its Occurrence in Madigan Gulf and its Possible Origin. (Contained in this volume.)

BONYTHON, W., and KING, D., 1955 (b). An Occurrence of Sulphur at Lake Eyre. (Contained in this volume.)

BONYTHON, ET ALIA, 1955 (c). Lake Eyre, South Australia. The Great Flooding of 1949-50. Roy. Geog. Soc. of Aust. (S.A. Branch), Report of the Lake Eyre Committee.

CROCKER, R. L., 1946. The Simpson Desert Expedition, 1939. Scientific Reports: No. 8—The Soils and Vegetation of the Simpson Desert and its Borders. Trans. Roy. Soc. S.A. **70** (2), pp. 235-258.

DAVID, T. W. E., 1932. Explanatory Notes to a New Geological Map of the Commonwealth of Australia, Sydney.

FENNER, C., 1952. Lake Eyre in Flood, 1950—Muds, Salts, etc. Trans. Roy. Soc. S.A. **75**, pp. 5-8.

FORBES, B. G., 1955. Proterozoic Sedimentary Magnesite of South Australia. Ph.D. Thesis, Adelaide University (unpublished).

JACK, R. L., 1915. Bulletin No. 5, Geological Survey of S.A., 1915.

LUDBROOK, N. H., 1953. Foraminifera in Sub-Recent Sediments at Lake Eyre, South Australia. Aust. Journ. Science, **16**, No. 3, pp. 108-109.

LUDBROOK, N. H., 1955. Microfossils from Pleistocene to Recent Deposits, Lake Eyre, South Australia. (Contained in this volume.)

MADIGAN, C. T., 1929. An Aerial Reconnaissance into the South-Eastern Portion of Central Australia. Proc. Roy. Geog. Soc. of S.A. **30**.

MADIGAN, C. T., 1930. Lake Eyre, South Australia. The Geog. Journal **76**.

MADIGAN, C. T., 1936. The Australian Sand-Ridge Deserts. Geog. Review **26** (2), 1936.

MADIGAN, C. T., 1938. The Simpson Desert and its Borders. Journ. and Proc. of the Roy. Soc. N.S.W. **71** (2), pp. 503-535.

MADIGAN, C. T., 1946. The Simpson Desert Expedition, 1939. Scientific Reports: No. 6—The Sand Formation. Trans. Roy. Soc. S.A. **70**, pp. 45-63.

WARD, L. K., 1946. Bulletin No. 23, Geological Survey of South Australia.

WHITTLE, A. W., and CHEBOTAREV, N., 1952. The Stratigraphic Correlation by Petrographic Methods Applied to Artesian Bores in the Lake Frome Area. Sir Douglas Mawson Anniversary Volume, University of Adelaide.

SOME ADDITIONS TO THE ACARINA-MESOSTIGMATA OF AUSTRALIA

BY *H. WOMERSLEY*

Summary

In the present paper a number of genera and species of mites belonging to the Mesostigmata, mostly new, are described or recorded from Australia. They were mainly from Queensland from soil litter and were largely collected by Dr. E. H. Derrick, to whom I am greatly indebted for the opportunity of studying and describing them. The types are in the South Australian Museum collections and where possible some paratypes in the Queensland Institute for Medical Research.

SOME ADDITIONS TO THE ACARINA-MESOSTIGMATA OF AUSTRALIA

By H. WOMERSLEY*

[Read 11 Aug. 1955]

SUMMARY

In the present paper a number of genera and species of mites belonging to the Mesostigmata, mostly new, are described or recorded from Australia. They were mainly from Queensland from soil litter and were largely collected by Dr. E. H. Derrick, to whom I am greatly indebted for the opportunity of studying and describing them. The types are in the South Australian Museum collections and where possible some paratypes in the Queensland Institute for Medical Research.

List of Genera and Species:

Family Macrochelidae
Euepicrius queenslandicus sp. nov.

Family Parasitidae
Pergamasus primitivus Ouds.

Family Pseudoparasitidae
Onchogamasus communis g. et sp. nov.

Family Neoparasitidae
Queenslandolaelaps vitzthumi g. et sp. nov.
Queenslandolaelaps berlesei sp. nov.
Antennolaelaps affinis g. et sp. nov.
Stylogamasus convexa g. et sp. nov.

Family Laelaptidae
Subfamily Hypoaspidinae
Coleolaelaps heteronychus sp. nov.
Subfamily Phytoseiinae
Primoseius macauleyi (Hughes) g. nov.
Typhlodromus cucumeris Ouds.
Subfamily Podocininae
Derrickia setosa Wom.

Family MACROCHELIDAE Vitzthum

Vitzthum, Graf H., 1930. Zool. Jahrb., Abt. f. Systematik, Bd. 59.

Genus EUEPICRIUS Womersley

Womersley, H., 1942. Trans. Roy. Soc. S. Aust., 66 (2): 170 (Type *Euepicrius filamentosus* Wom.).

This genus and species were erected for specimens collected in moss from the vicinity of Adelaide, South Australia, in 1938, while a single female was recorded at the same time from Waimamaku, New Zealand.

* Acarologist, South Australian Museum.

In the long and slender first legs and general form the genus shows a superficial resemblance to *Epicrius* (Epicriidae), but differs in the absence of claws and caruncle on the first legs, the presence of a distinct peritreme, a 3-tined seta on the palpal tarsus and in the structure of the ventral shields.

The following new species was isolated by Mr. Robert Domrow from litter collected by Dr. E. H. Derrick at Brookfield, near Brisbane, between May and July, 1949.

Euepicrius queenslandicus sp. nov.

Fig. 1, A-I

Description: *Female Holotype*—A small and lightly chitinised species of rotund form. Length of idiosoma 352μ, width 240μ. Dorsal shield lightly rugose, divided as figured, the anterior part the longer and furnished with 17 pairs of setae, the vertical pair 34μ long, stout ciliated and arising from strong tubercles, the second pair each lateral of the verticals to 20μ and also on tubercles but plain and slender, the other setae to 30μ plain, slender and tapering; the posterior portion of the dorsal shield with 14 pairs and 4 median setae of which the posterior pair are 39μ long, stout, blunt and ciliated, the others are long, slender, plain and slightly filamentous, to 32μ, being shorter and less filamentous than in *filamentosus*. Venter: tritosternum normal; no pre-endopodal shields; sternal shield about as wide as long medially, laterally extending to between coxae III and IV, with 4 pairs of setae and 2 pairs of pores, anterior margin sinuous, posterior margin deeply excavate; genital shield as wide basally as long, with one pair of setae, posterior margin truncate and only narrowly separated from ventri-anal shield; ventri-anal shield extending across opisthosoma, with 9 pairs of setae besides the paranals, the 3 lateral on each side long, fine and filamentous, to 70μ long, the posterior pair to 48μ long, thick and ciliated, the others short, plain and tapering to 22μ, the paranal setae short and subequal; the peritremal tube is lightly corrugated and the stigma lies between coxae III and IV, the shield extends backwards to just beyond coxae IV, while the tube anteriorly crosses over to the dorsum at the level of coxae II; behind coxae IV there is a fine suture line where the dorsal shield coalesces with the ventri-anal shield. Leg I 592μ long, slender and tactile, tarsus without caruncle or claws, but with long and fine tactile setae; II-IV stouter with caruncles and claws, II 313μ, III 288μ, IV 378μ. Chelicerae as figured, fixed finger with 5 or 6 small blunt teeth, movable finger with 4 teeth. Tectum as figured, variable, with median mucro and lateral points between which on each side are two smaller points.

Male Allotype—Facies as in female. Length of idiosoma 352μ, width 196μ. Legs: I 528μ long, II 320μ, III 304μ, IV 352μ; femur of leg II with strong, hooked apophysis as figured and a small tubercle on the genu. Venter: sternal, metasternal and genital shields coalesced, with 5 pairs of setae and 2 pairs of pores; ventri-anal shield as in female. Chelicerae as figured, fixed finger with three smallish teeth, movable finger with one strong tooth and a long, slender spermatophore carrier which is as long again as the finger and is slightly swollen at the tip. Tectum variable as in female.

Remarks—This species is somewhat smaller than *filamentosus* and differs in lacking the very long, whip-like filamentous setae on the dorsum and on the ventri-anal shield, except for the three lateral pairs. The dorsal setae are otherwise short and simple as are the other ventri-anal setae. The chelicerae, tectum and leg II of the male are similar to those of *filamentosus*.

The holotype female and allotype male and several paratypes are in the collection of the South Australian Museum and two paratypes in the Queensland Institute for Medical Research.

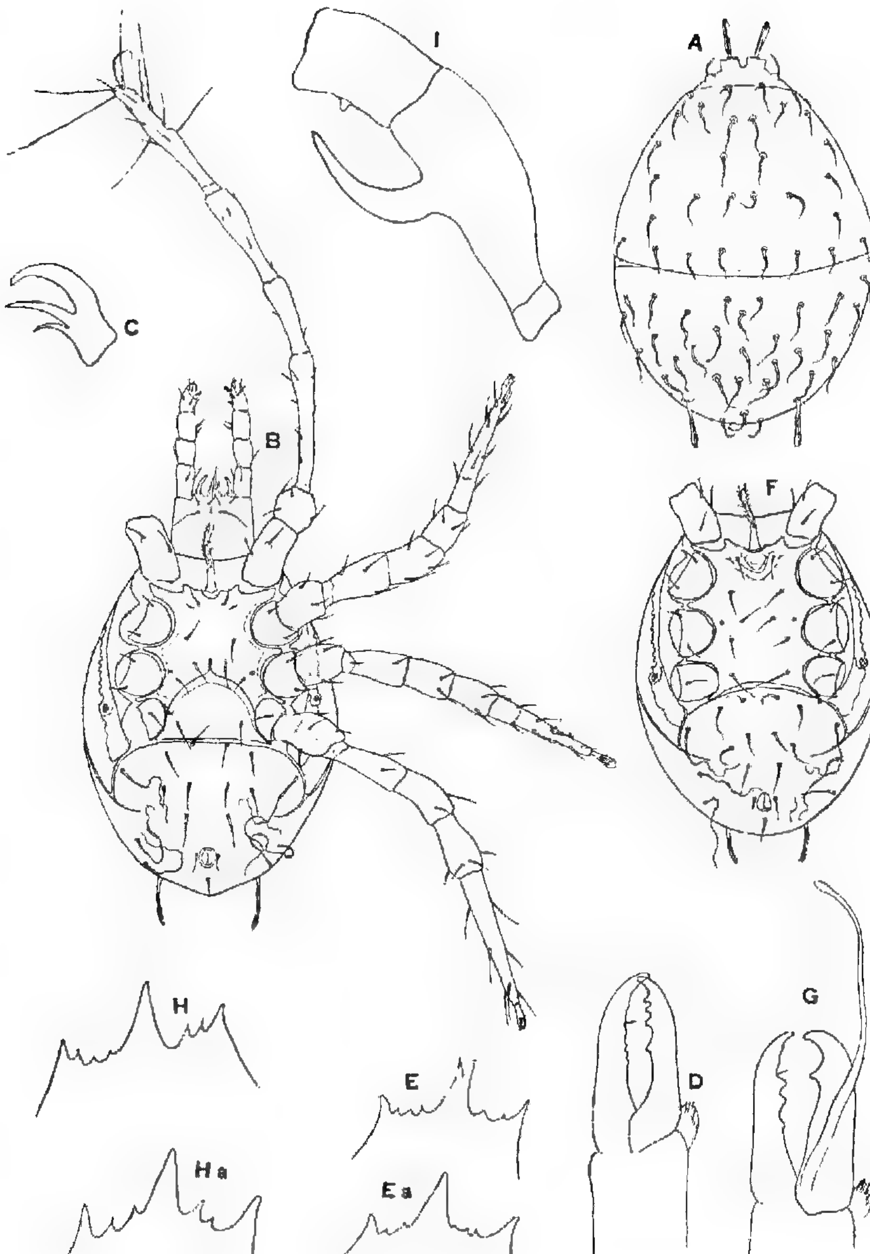


Fig. 1 A-I—*Euepicrius queenslandicus* sp. nov. A-E Female: A, dorsum, B. venter, C. specialised seta on palpal tarsus, D. chelicerae, E. two views of tectum; F-H Male: F. venter, G. chelicerae, H. two views of tectum, I. apophysis on femur of leg II.

Family PARASITIDAE Oudemans

Oudemans, A. C., 1901. Notes on Acari; Third Series. Tijdschr. ned. dierk Ver. (2), III, No. 2: 59.

Genus PERGAMASUS Berlese

Berlese, A., 1903. Redia 1: 235 (Type *Acarus crassipes* Linn. 1759).

Pergamasus primitivus (Ouds)

Fig. 2 A-I

Parasitus primitivus Oudemans, 1904. Entom. Ber., 1: 140.
Gamasus effeminatus Berlese, 1905. "Acari nuovi," Manipl. IV, Redia 2: 165.
Gamasus (Pergamasus) effeminatus Berlese, 1906. Mon. d. Gamasus, Redia 3: 193-201.
Gamasus primitivus Vitzthum, 1926. Treubia 8: 3.

This species was originally described by Oudemans from Brazil, and later recorded by Berlese from Java. Berlese was unable to find other than insignificant differences between the Javanese and Brazilian specimens. In 1926 Vitzthum recorded it from Batavia and Tjibodes.

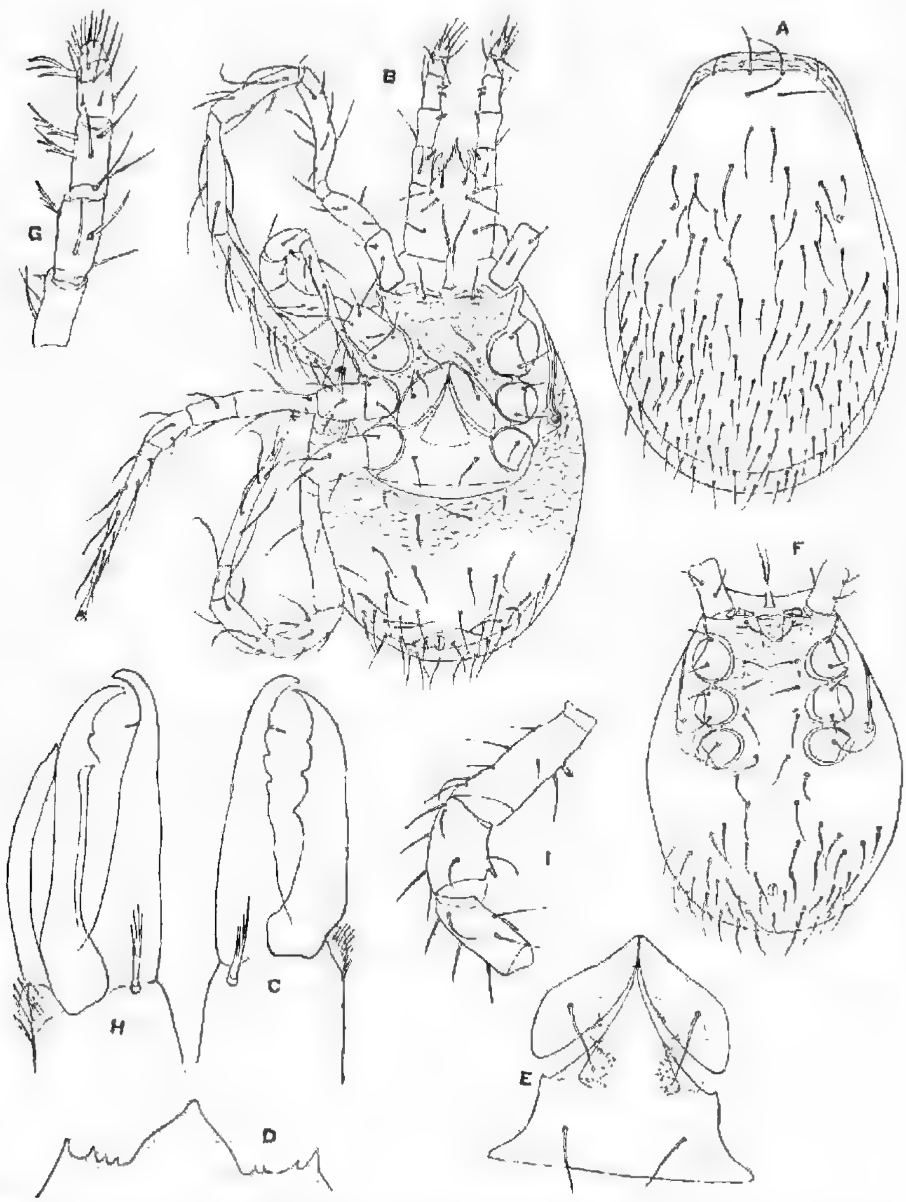


Fig. 2 A-I—*Pergamasus primitivus* (Ouds). A-E Female: A. dorsum, B. ventral view, C. chelicerae, D. tectum, E. genitalia; F-I Male: F. venter, G. palp, H. chelicerae, I. femur genu and tibia of leg I.

A series of specimens of both sexes were obtained from litter from Brookfield, Queensland, 11th June, 1949 (coll. E. H. Derrick). Figures drawn from this Australian material are now given.

Family PSEUDOPARASITIDAE Vitzthum

Vitzthum, Graf H., 1941. In Bronn's Tierreich, 5, *Acarina*: 757.

Genus ONCHOGAMASUS nov.

Pseudoparasitidae. Dorsal shield entire with fine punctate reticulations, only slightly and narrowly underlapping the venter. Pre-endopodal shields present. Sternal and metasternal shields coalesced, sternal deeply incised posteriorly. Ventri-anal shield only moderately expanded behind coxae IV. Tectum spike-like. Labial cornicles 2-segmented, the apical being small and cone-like and inserted into apex of basal. Tarsi of leg II with three strong accessory claw-like spines.

Genotype *Onchogamasus communis* sp. nov.

Onchogamasus communis sp. nov.

Fig. 3 A-G

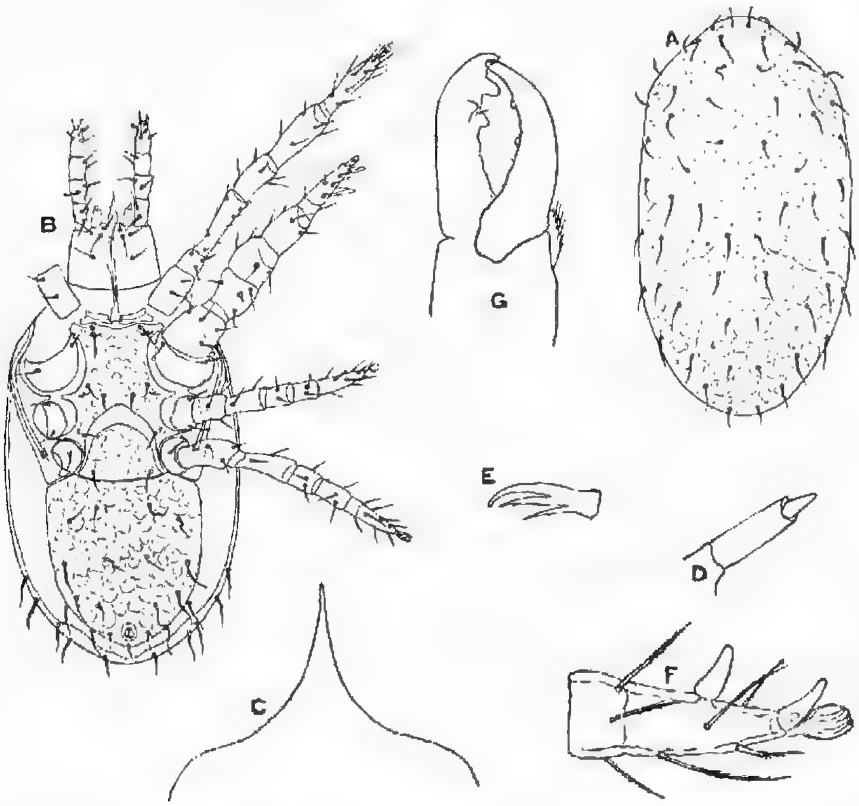


Fig. 3 A-G—*Onchogamasus communis* g. et sp. nov. Female: A. dorsum, B. ventral view, C. tectum, D. labial cornicle, E. specialised seta of palpal tarsus, F. tarsus I, G. chelicerae.

Description: *Female Holotype*—Shape of body ovoid. Length of idiosoma 559μ, width 338μ. Dorsal shield with punctate reticulations, narrowly underlapping the venter laterally and posteriorly, furnished with 30 pairs of setae to 45μ long which, except for the verticals and laterals, are simple, the verticals

and laterals being slightly ciliated. Venter: tritosternum normal; a pair of pre-endopodal shields present; sternal and metasternal shields coalesced, longer than wide, with four pairs of setae of which the first pair are ciliated, the others simple, with three pairs of pores, posterior margin deeply incised; genital shield as wide posteriorly as long with a pair of short, simple setae, posterior margin only just separated from ventri-anal shield; ventri-anal shield longer than wide with 6 pairs of ciliated setae to 45μ long; all three ventral shields strongly reticulated; peritremal shields fused with exopodal shields, the peritremal tube runs forward from the stigma between coxae III and IV to between coxae I and II, where it overlaps slightly on to the dorsum. Legs short, I, III and IV slender, II much thicker and stronger and furnished on femur with a short, stout spine and on tarsus with three strong claw-like accessory spines, leg I 416μ long, II 364μ, III 260μ, IV 364μ, all with caruncle and paired claws. Chelicerae as figured, fixed finger with three strong, blunt teeth, movable finger with two small, blunt teeth. Tectum as figured with a median spine-like mucro. Specialised seta on palpal tarsus 3-tined. Labial cornicles peculiar, 2-segmented, the apical being small, cone-like and inserted into the basal.

Locality—One single female, the holotype, from soil debris, Brookfield, Queensland, 21st May to 2nd June, 1949 (coll. E. H. Derrick). The type in the South Australian Museum.

Family NEOPARASITIDAE Oudemans

Oudemans, A. C., 1939, *Zool. Anz.* 126 (1-2): 21.

Genus QUEENSLANDOLAELAPS nov.

Neoparasitidae with the tectum trident-like, the median tine or mucro arising from below. Tarsi of leg I with paired claws and short caruncle. Dorsal shield entire. In female sternal and metasternal shields more or less coalesced. Pre-endopodal shields present. In male with a strong apophysis on femur of leg IV and a long whip-like spermatophore carrier on movable finger of chelicerae.

Genotype *Queenslandolaelaps vitzthumi* sp. nov.

Queenslandolaelaps vitzthumi sp. nov.

Fig. 4 A-H

Description: *Female Holotype*—Shape oval, but the sides rather parallel. Length of idiosoma 585μ, width 338μ. Lightly chitinised. Dorsal shield as figured, not entirely covering dorsum, lightly reticulate, with 38 pairs of setae to 52μ long and simple, except the posterior and postero-laterals, which are lightly ciliated. Venter: tritosternum present and normal: a pair of transverse pre-endopodal shields present; sternal and metasternal shields coalesced, the whole longer than wide laterally where it extends to between coxae III and IV, with deeply incised posterior margin, with four pairs of setae and two pairs of pores, the third pair of sternal setae are situated submedially; genital shield as wide basally as long, with only one pair of setae, posterior margin straight and only slightly separated from the anterior margin of the ventri-anal shield, anterior margin rounded; ventri-anal shield about twice as wide where it is expanded behind coxae IV, laterally and posteriorly rounded, with 7 pairs of setae in addition to the paranals; peritremal shields coalesced with the exopodal shields and extending only slightly past coxae IV to the shoulders of the ventri-anal shield; stigma lying between coxae III and IV and the peritremal tube running forwards to coxae I. Legs not longer than body and not excessively thick; I 572μ long, II 429μ, III 338μ, IV 496μ, all tarsi with short caruncle and paired claws, no special armature on coxae or on leg II. Chelicerae as figured, fixed finger with two large basal teeth and four smaller teeth before the apex,

movable finger with three teeth. Tectum peculiar and suggestive of the Veigaiaidae, trident-like with the median tine twice as long as the laterals and apparently arising from below, all three tines expanded and denticulate apically.

Male Allotype—General facies as in female. Length of idiosoma 546μ, width 325μ. Dorsum as in female. Venter: tritosternum and pre-endopodal shields as in female; sternal, metasternal and genital shields coalesced and narrowly separated from ventri-anal shield, with 5 pairs of setae; ventri-anal and peritremal shields as in female. Legs as in female, except that II has a

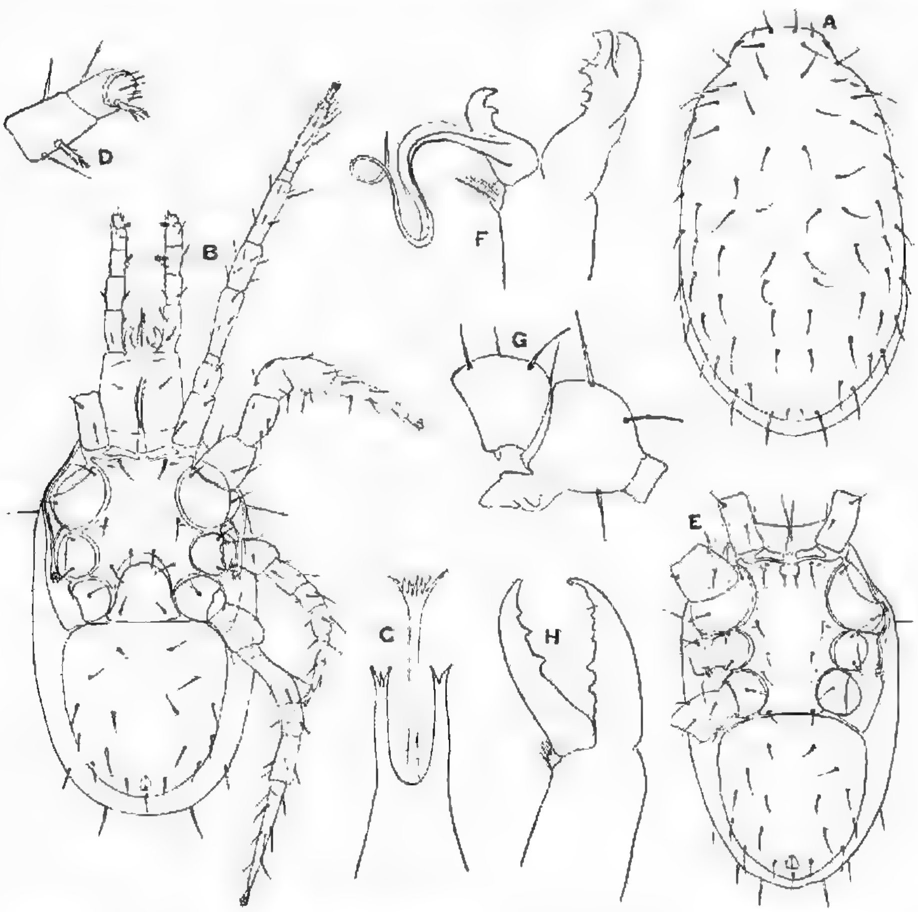


Fig. 4 A-H—*Queenslandolaelaps vitzthumi* g. et sp. nov. A-D, and H Female: A. dorsum, B. ventral view, C. tectum, D. tip of palp, H. chelicerae; E-G Male: E. venter, F. chelicerae, G. femur and genu of leg I.

strong apophysis on the femur and a small tubercular process on the genu, I 559μ long, II 403μ, III 338μ, IV 520μ. Chelicerae as figured; fixed finger twice as long as movable finger, thick and stout to apex which is longitudinally split with three strong inner teeth; movable finger short with one strong tooth and a long, curled, whip-like spermatophore carrier. Tectum as in female.

Locality—The female holotype, the male allotype and one paratype male from soil debris, Brookfield, Queensland, 31st May to 10th June, 1949 (coll. E. H. Derrick). In the South Australian Museum collection.

Remarks—In having a 3-tined seta on the palpal tarsus this genus belongs to the Neoparasitidae, although in the peculiar structure of the tectum it bears

some resemblance to the Veigaiaidae in which the palpal seta is 4-tined and the dorsal shield incised laterally.

Beside the genotype the genus will also contain the following species, also from Queensland.

Queenslandolaelaps berlesei sp. nov.

Fig. 5 A-D

Description: Female Holotype—Shape oval, sides gradually curving inwards at about one-third from the front. Moderately well chitinised. Length of idiosoma 578μ, width 380μ. Dorsal shield entire, covering all the dorsum, strongly reticulate with imbricate markings, with 34 pairs of slender ciliated and flagellate setae to 104μ long. Venter: tritosternum and a pair of pre-endopodal transverse shields present; sternal and metasternal shields coalesced,

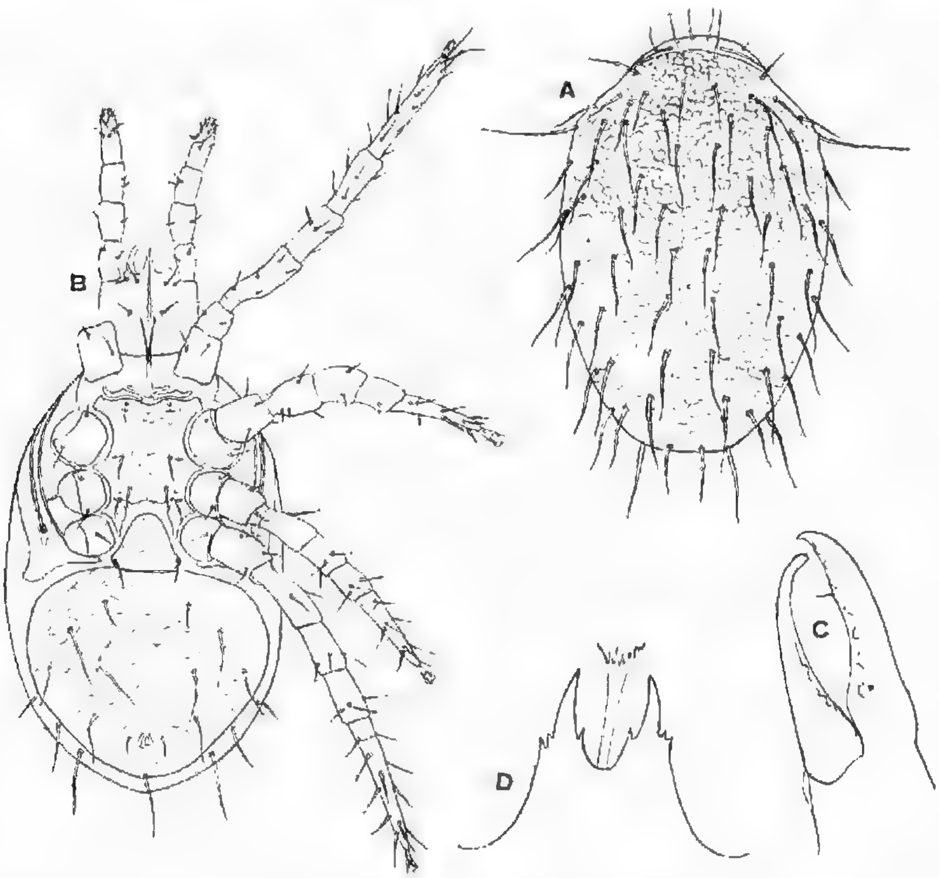


Fig. 5 A-D—*Queenslandolaelaps berlesei* sp. nov. Female: A. dorsum, B. ventral view, C. chelicerae, D. tectum.

although the metasternals are only narrowly joined to the sternal (see Fig. 5 B) and the metasternal setae are on the sternal portion; sternal shield reticulate; genital shield as wide basally as long, with straight posterior and rounded anterior margin, with one pair of setae; ventri-anal shield as wide as long and covering most of the opisthosoma, with light imbricate markings, with 5 pairs of long setae besides the paranals, the adanal setae very short compared with the postanal; peritremal shield not coalesced with the exopodal, rather broadly expanded just behind coxae IV, stigma between coxae III and IV. Legs not

excessively thick, unarmed, all tarsi with short caruncle and paired claws. I 520μ long, II 390μ, III 366μ and IV 533μ. Chelicerae as figured, fixed finger with 7 blunt teeth, movable finger with two. Tectum peculiar, trident-like with the median tine only slightly longer than the laterals, arising from below and with its apex expanded and denticulate, the lateral tines are dissimilar to the median and are cone-like with one inner and two outer small teeth. Seta on palpal tarsus 3-tined.

Male—Unknown.

Locality—Described from a solitary specimen, the holotype, from soil debris from Brookfield, Queensland, between 31st May and 10th June, 1949 (coll. E. H. Derrick). In the South Australian Museum.

Remarks—In the structure of the tectum and the ventral shields this species is closely related to the preceding and clearly belongs to the same genus. From *fitzthumi* it differs in the structure of the tectum, the dentition of the movable finger of the chelicerae, the narrow bridge uniting the sternal and metasternal shields, the wider separation of the third pair of sternal setae, the much wider ventri-anal shield, the more imbricate reticulations on the dorsum and the much longer dorsal setae.

Genus Antennolaelaps nov.

Neoparasitidae. Male. Oval and strongly chitinised. Legs long and slender, especially I, which is tactile without caruncle and claws, II-IV with these. Dorsal shield entire and underlapping on to venter from level of coxae II backwards, but not fused with ventral shields. Pre-endopodal shields distinct, sternal, metasternal and genital shields coalesced, with 5 pairs of setae and 3 pairs of pores, separated by a suture from the expanded ventri-anal. Peritremal tube corrugated. Tectum with a long median apically trifurcate mucro. Female unknown.

Genotype *Antennolaelaps affinis* sp. nov.

Antennolaelaps affinis sp. nov.

Fig. 6 A-F

Description: Male Holotype—Oval, strongly chitinised and brown species. Length of idiosoma 491μ, width 364μ. Dorsal shield entire and underlapping on to venter from level of coxae IV backwards, with 23 pairs of setae to ?μ long (mostly missing in both specimens), on the underlap posteriorly is one pair of setae to 59μ long. Venter: tritosternum present and normal, its base inserted between the distinct pair of pre-endopodal shields; sternal, metasternal and genital shields coalesced, with three pairs of setae and three pairs of pores, separated from ventri-anal shield by a thin, straight suture on level of posterior margin of coxae IV; ventri-anal shield expanded behind coxae IV, triangular, not coalesced with the underlap of dorsal shield, with 7 pairs of setae besides the paranals which are very short; peritremal shield fairly narrow and posteriorly reaching to middle of coxae IV, stigma between coxae III and IV, the tube markedly corrugated and running on to the dorsum on level of coxae II. Legs long and slender, I 783μ long, tactile, without caruncle and claws, tibia and tarsus with long, slender, fine setae; II 572μ long, normal with caruncle and claws, femur with a strong subapical apophysis flanked by a small one, genu also with a similar small apophysis, setae on tarsus long and slender; III and IV to 515μ and 936μ respectively, with caruncle and claws and long slender setae. Chelicerae as figured, fixed finger with 3 fairly strong teeth, movable finger with one tooth and a long, slender spermatophore carrier of its own length. Tectum as figured, with a peculiar median apically trident-like mucro flanked on each side by two or three teeth. Specialised seta on palpal tarsus 3-tined.

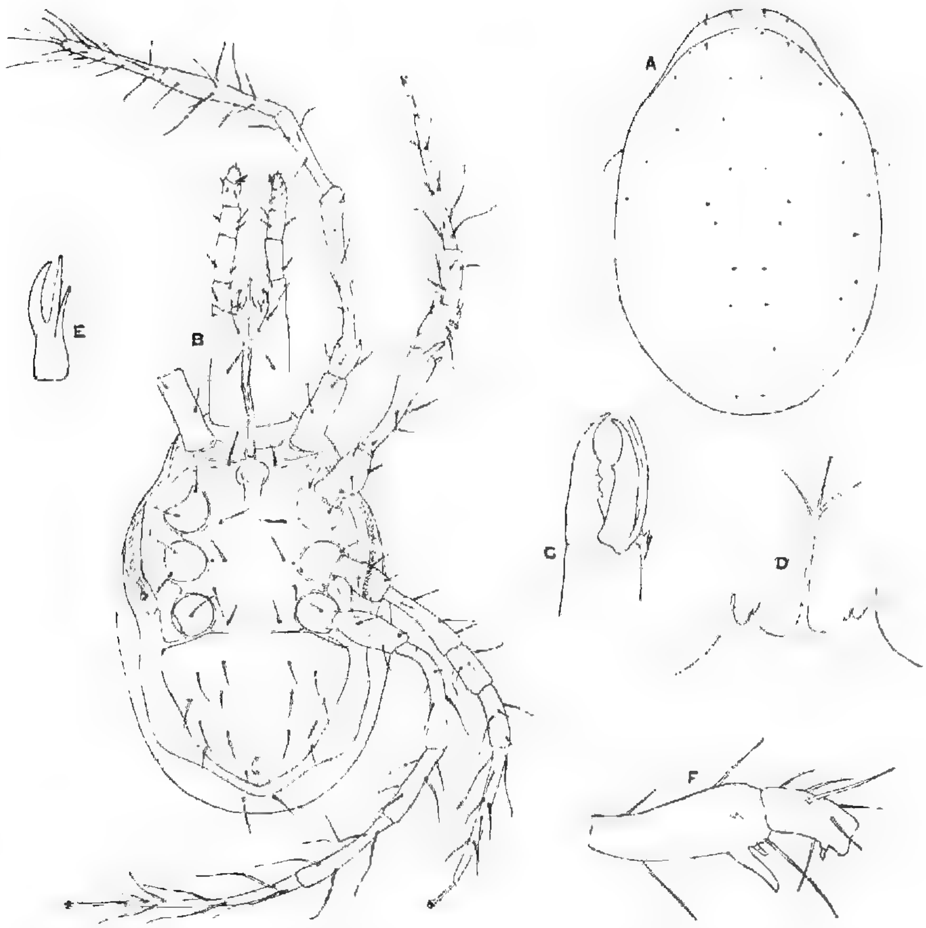


Fig. 6 A-F. *Antennolaelaps affinis* g. et sp. nov. Male: A. dorsum, B. ventral view, C. chelicerae, D. tectum, E. seta of palpal tarsus, F. femur and genu of leg I.

Female—Unknown.

Locality—The holotype and one paratype from litter from Brookfield, Queensland, 31st May to 10th June, 1949 (coll. E. R. Derrick).

Genus Stylogamasus nov.

Neoparasitidae, near to *Hydrogamasus* but without metapodal shields, with sternal and metasternal shields coalesced, combined shield deeply excavate posteriorly. Dorsal shield entire, underlapping ventrally. Peritremal tube thick. Tectum trispinous.

Genotype *Stylogamasus convexa* sp. nov.

Stylogamasus convexa sp. nov.

Fig. 7 A-I

Description: Female Holotype—Shape of idiosoma sub-oval. Length of idiosoma 572μ, width 416μ. Dorsal shield entire, lightly reticulate, entirely covering the dorsum and underlapping narrowly to the margin of the ventri-anal shield; furnished with 32 pairs of setae, the second and the humeral pairs and the three postero-median pairs of which are straight and strongly ciliated,

the rest simple and flagellate to 78μ long. Venter: tritosternum normal, a pair of pre-endopodal shields present; metasternal *cum* sternal shield longer than wide with 4 pairs of setae and 3 pairs of pores, the first two pairs of setae are ciliated, the others simple; genital shield as wide posteriorly as long, with punctate reticulations, with one pair of slightly ciliated setae, posterior margin separated only slightly from ventri-anal shield; ventri-anal shield as wide anteriorly as long with 6 pairs of ciliated setae to 65μ long in addition to the paranals; with imbricate markings; peritremal tube wide, running from between coxae III and

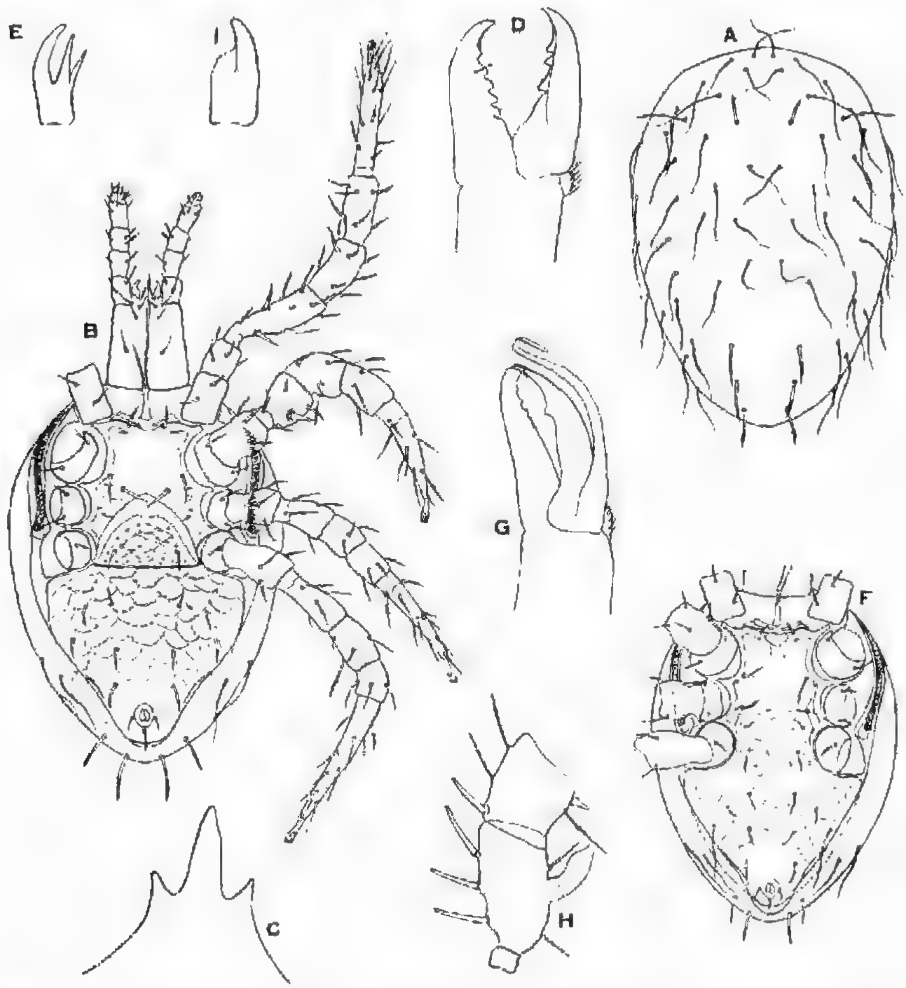


Fig. 7 A-I *Stylolaelaps convexa* g. et sp. nov. A-E Female: A. dorsum, B. ventral view, C. tectum, D. chelicerae, E. seta of palpal tarsus; F-I Male: F. venter, G. chelicerae, H. femur and genu of leg I, I. labial cornicle.

IV forwards to coxae I; exopodal shields fused but together separated from peritremal shield. Legs: I 624μ long, II 468μ, III 442μ, IV 559μ; femur and genu of leg II each with a strong and stout spine-like seta. Chelicerae as figured, fixed finger with 5 fairly strong teeth and a simple seta, movable finger with 5 similar teeth. Tectum trispinous. Specialised seta on palpal tarsus 3-tined.

Male Allotype—Facies as in female. Length of idiosoma 455μ, width 364μ. Venter: pre-endopodal shields present; sternal, metasternal, genital and ventri-anal shields fused to form a single holoventral shield with 11 pairs of

setae, the metasternal pair short and simple to 20μ long, the postero-lateral two pairs simple and flagellate to 91μ, the rest short and ciliated to 32μ long. Legs: I 624μ long, II 468μ, III 390μ, IV 550μ; femur of leg II with a large apophysis and three strong spines, genu with two strong spines. Chelicerae as figured, fixed finger with 5 small teeth, movable finger with one strong tooth and a short apically recurved spermatophore carrier. Tectum as in female.

Locality—Holotype female, allotype male and five paratype females from soil debris, Brookfield, Queensland, 31st May to 10th June, 1949 (coll. E. H. Derrick). In the collection of the South Australian Museum.

Family LAELAPTIDAE Berlese

Berlese, A., 1892. Acari, Myriapoda et Scorpiones ital. reperta; Mesostigmata: 30.

Subfamily HYPOASPIDINAE Vitzthum

Vitzthum, Graf H., 1941. In Bronn's Klass. u. Ordnungen, Bd. V, Abt. IV, Bh. 5.

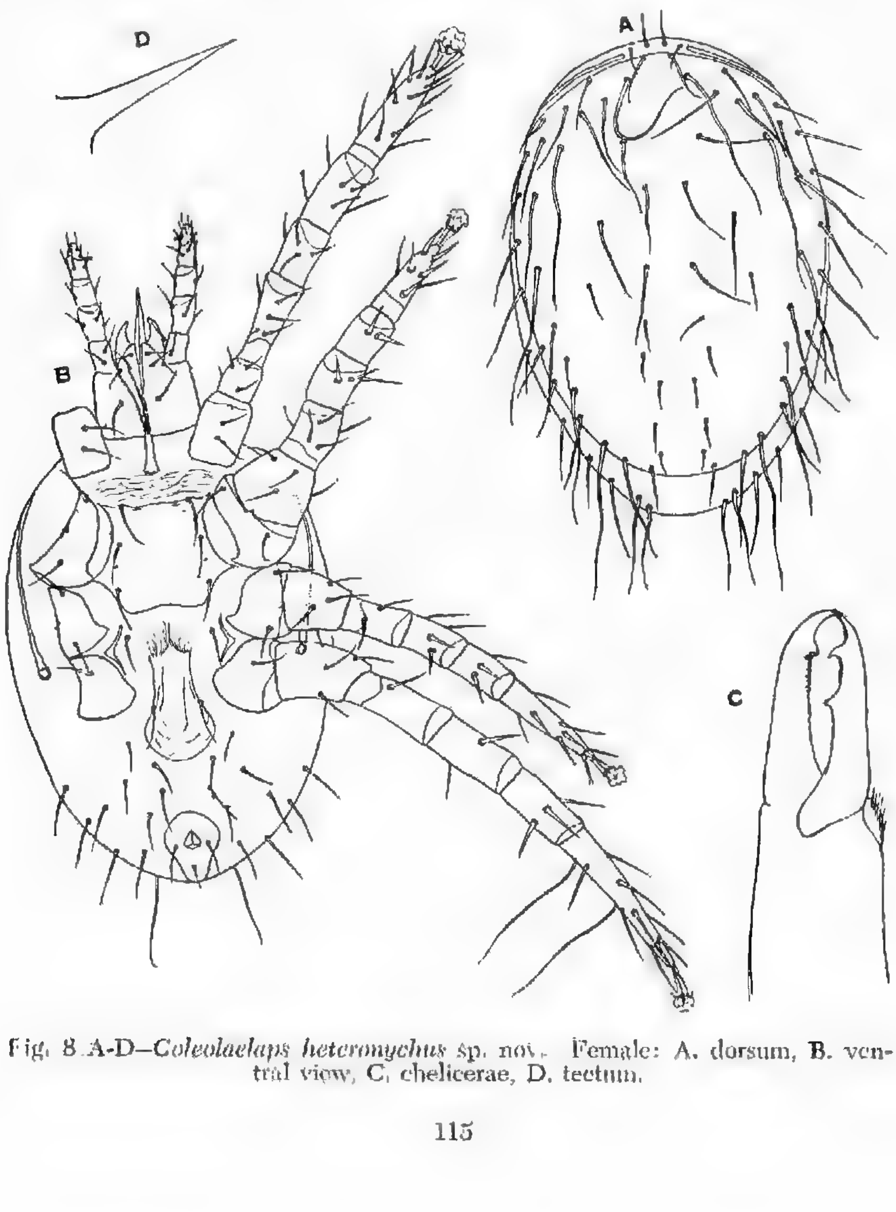


Fig. 8 A-D—*Coleolaelaps heteronychus* sp. nov. Female: A. dorsum, B. ventral view, C. chelicerae, D. tectum.

Genus COLEOLAELAPS Berlese

Berlese A., 1914. Redia 10: 141. (Type *Laelaps* (*Iphis*) *agrestis* Berlese, 1887.)

Coleolaelaps heteronychus sp. nov.

Fig. 8 A-D

Description: Female Holotype—A fairly lightly chitinised species. Length of idiosoma 675μ, width 456μ. Dorsal shield entire, not completely covering dorsum, 585μ long by 416μ wide, with 34 pairs of short to long and very long, slender simple setae, the lateral and sublateral setae reaching to 247μ in length. Venter, tritosternum normal with ciliated lacinia; no pre-endopodal shields; sternal shield about as long as wide and extending posteriorly to middle of coxae III, with lightly incurved posterior margin, with 3 pairs of setae and 2 pairs of pores, metasternal shields represented only by the setae; genital shield flask-like in shape with one pair of setae and light reticulations, well separated from anal shield; anal shield pear-shaped with 3 paranal setae; laterad of the anal and genital shields there are 5 setae on each side and between these shields there are two pairs of setae. Peritreme long and slender with the stigma lying between coxae III and coxae IV, overlapping dorsally near coxae II. Legs fairly thick, only IV slightly longer than body; the setae on II-IV are rather stouter than on I; all tarsi with caruncle, claws and pad; I 624μ long, II 520μ, III 572μ, and IV 754μ. Chelicerae as figured, fixed finger with a subapical tooth followed by a series of minute rounded tuberculations, movable finger with two strong teeth the distance between which equals that between apex and first tooth. Tectum lancet-like as figured.

Male—Unknown.

Locality—From a "Black Beetle" *Heteronychus sanctae-helenae* M. Edw., Maclean, New South Wales, 11th Feb., 1954 (coll. A. M. Harvey).

Remarks—Described from the holotype and one paratype in the collection of the South Australian Museum.

Subfamily PHYTOSEIINAE Berlese

Berlese, A., 1916. Redia 12: 33

Genus PRIMOSEIUS nov.

Allied to *Lasioseius* Ber., subgenus *Zercoseius* Berl., but characterised therefrom by the sternal shield having only two pairs of setae, the third pair being on distinctly separated round shieldlets; the metasternal shields only represented by the setae.

Genotype *Lasioseius* (*Zercoseius*) *macauleyi* Hughes 1948.

To this genus will also belong *Lasioseius* (*Zercoseius*) *graeri* Hughes 1948. In her description of *macauleyi* Mrs. Hughes refers to the small shieldlets carrying the third pair of sternal setae as the metasternal shields, but according to Trägårdh's interpretation of the ventral shields of the Mesostigmata and their attendant setae, the fourth pair of setae are the metasternal setae and the small shields in front of these with the third pair of setae can only be parts of the sternal shield which have become separated.

Primoseius macauleyi (Hughes)

Fig. 9 A-E

Lasioseius (?*Zercoseius*) *macauleyi* A. M. Hughes, 1948. The Mites associated with stored products. H.M. Stationary Office, London, p. 146, fig. 112.

This species was described by Mrs. Hughes from sifted oats and detritus from warehouse floors in England and Northern Ireland.

A number of specimens which cannot be distinguished specifically from the original description and figures of *macauleyi* have recently been collected from bark scrapings of logs at Port Adelaide, South Australia, January, 1954. The

logs had been imported from Western Australia and the men handling them complained of biting and irritation. Whether or not the trouble was due to this particular species is not certain. however, for several other species of mites were also present in numbers, including *Typhlodromus cucumeris* Ouds., *Garmania nesbitti* Wom., *Lasioseius* (Z.) *boomsmai* Wom. and *Tyrophagus castellanii* Hirst., the last being well-known as the cause of "copra itch".

The figures given in the present paper are drawn from the above Australian material.

Genus Typhlodromus Scheuten

Scheuten, A.; 1857. Arch. Naturgesch. 23: 111.

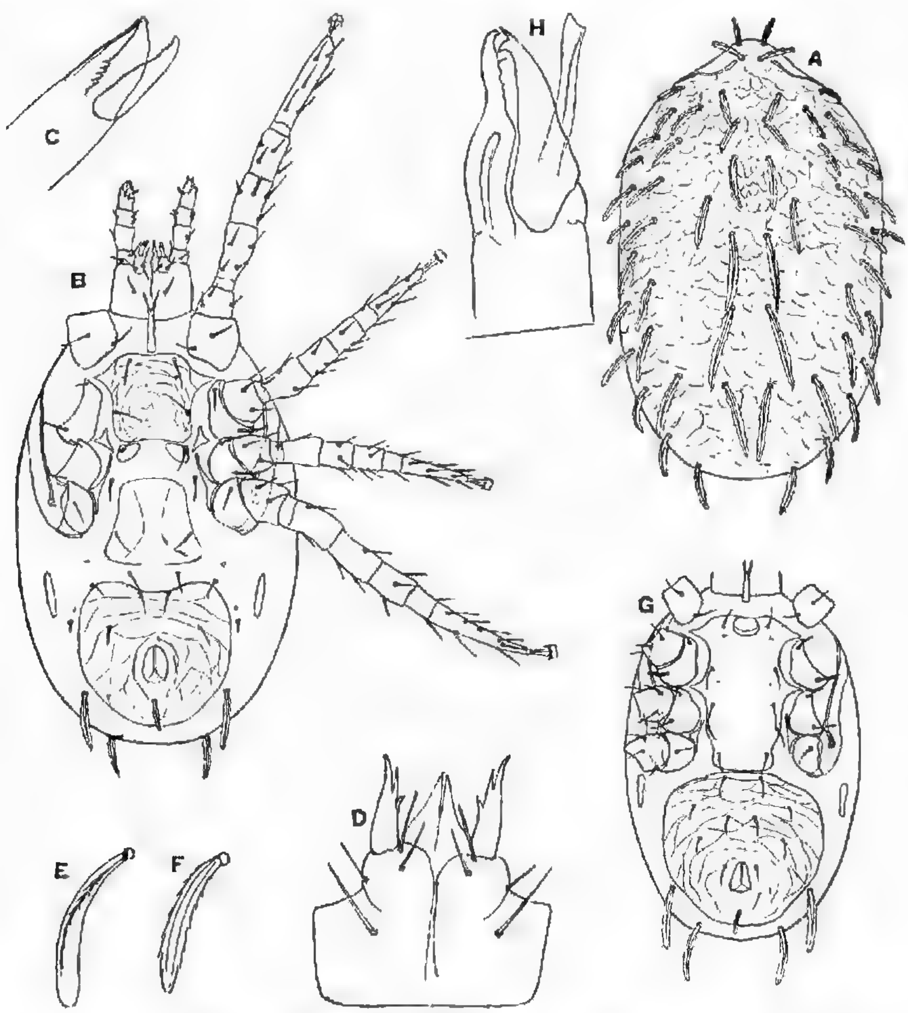


Fig. 9 A-H—*Primoseius macauleyi* (Hughes) A-F Female: A, dorsum, B, ventral view, C, chelicerae, D, labial cornicles, E. and F. two views of dorsal setae; G-H, Male: G. venter, H. chelicerae.

Typhlodromus cucumeris Oudemans

Fig. 10 A-C

Typhlodromus cucumeris Ouds., 1930, Ent. Ber., Amst. 8 (172): 69-70; Nesbitt, 1951, Zool. Verh. Leiden, No. 12: 23; Cunliffe and Baker, 1953, Pinellos Biol. Lab. Publ. No. 12: 15; Womersley, 1954, Aust. J. Zool. 2 (1): 175-6.

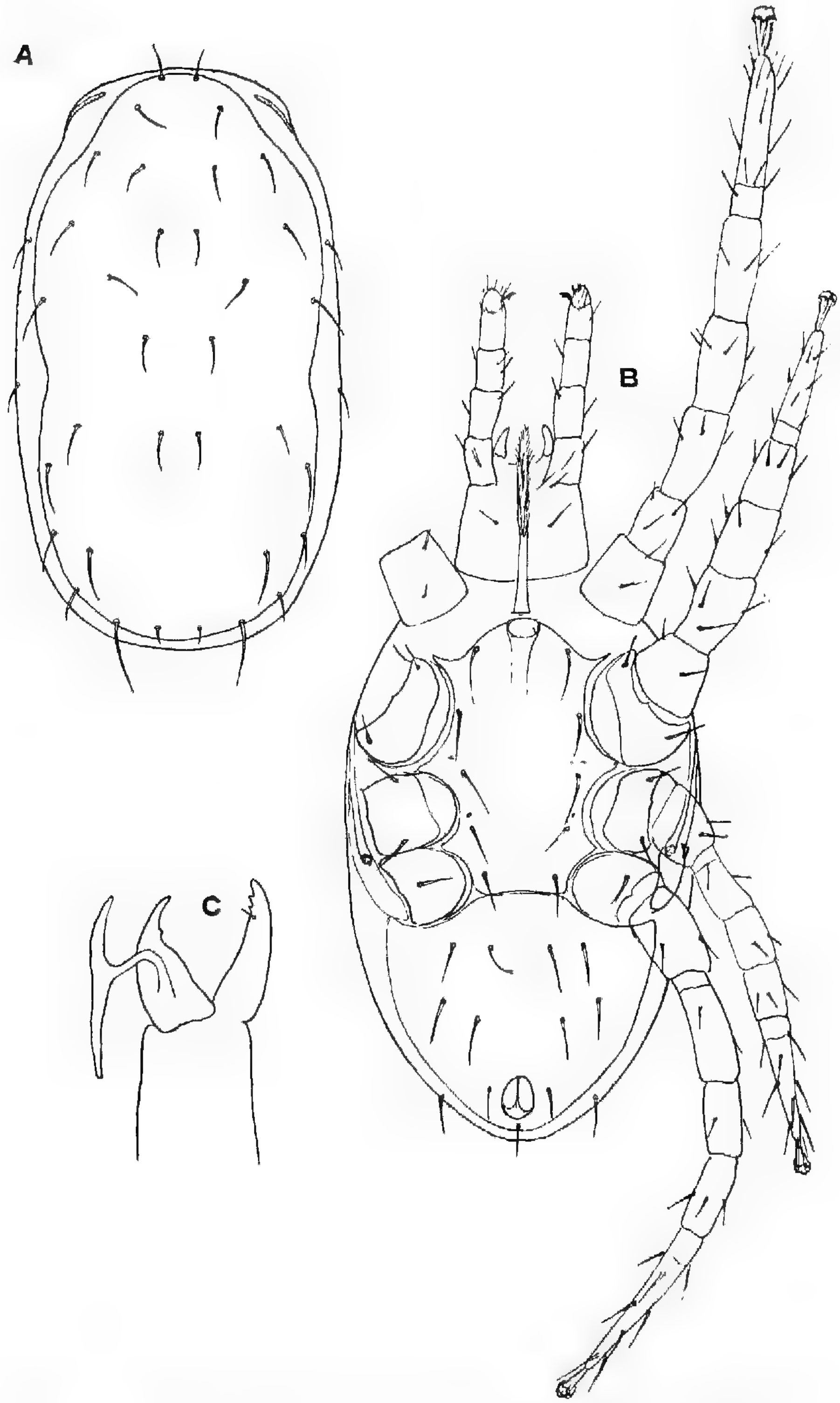


Fig. 10 A-C—*Typhlodromus cucumeris* Ouds. Male: A. dorsum, B. ventral view, C. chelicerae.

Description of Male Allotype—Facies generally as in female. Length of idiosoma 273μ, width 156μ. Dorsal shield lightly reticulated with setation as in female; D_1 14μ, D_2 14μ, D_3 14μ, D_4 17μ, D_5 17μ, D_6 8μ; M_1 17μ, M_2 29μ; L_1 20μ, L_2 17μ, L_3 17μ, L_4 22μ, L_5 20μ, L_6 20μ, L_7 17μ, L_8 14μ, L_9 36μ; S_1 17μ, S_2 17μ. Venter: tritosternum but no pre-endopodal shields present; sternal, metasternal and genital shields coalesced with 5 pairs of setae and 3 pairs of pores; ventri-anal shield expanded behind coxae IV, with rounded sides and 4 pairs of setae besides the paranals as in the female. Chelicerae as figured, the movable finger with a peculiar T-shaped spermatophore carrier much as in *T.(N.) barkeri* Hughes, the cross bar of which is longer than the chela itself. Legs as in female, I 273μ long, II and III 195μ, and IV 273μ.

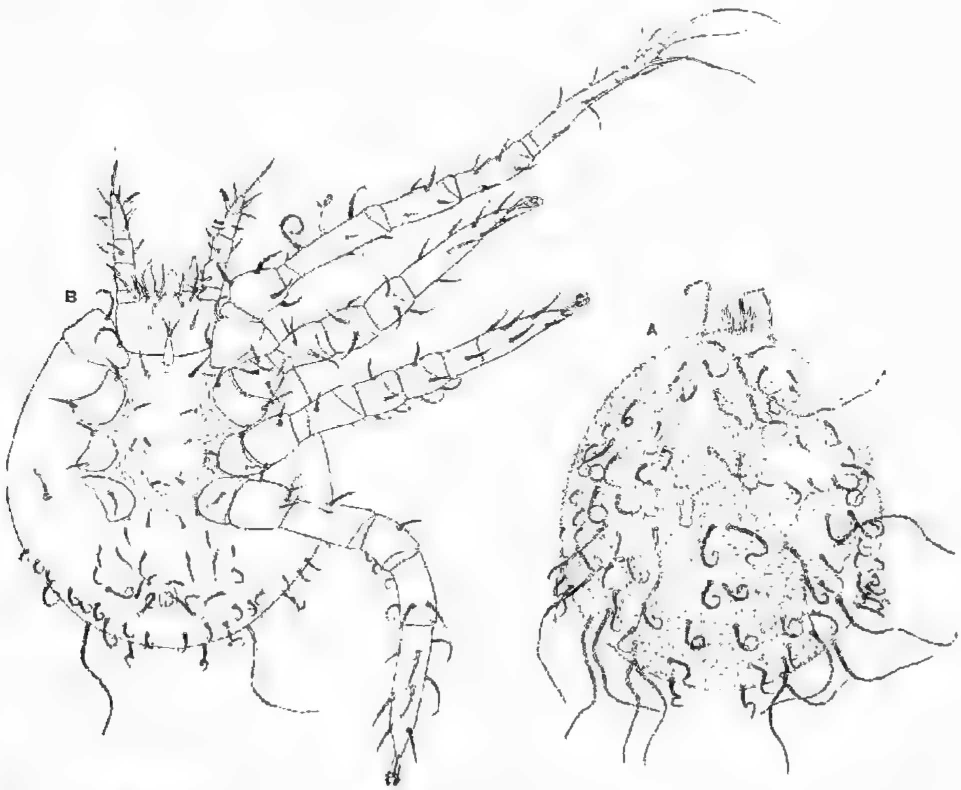


Fig. 11 A-B—*Derrickia setosa* Womersley Deutonymph: A. dorsum, B. ventral view.

Subfamily Podocininae Berlese

Berlese, A., 1916.

Genus Derrickia Womersley

Womersley, H., 1956. Jour. Linn. Soc. London, Zool. XLII, No. 288.

Genotype *Derrickia setosa* Wom. (protonymph).

Description of Deutonymph—General facies as in the protonymph. Length of idiosoma 650μ, width 546μ. Dorsal shield entirely covering the dorsum with the setation as in the protonymph; the antero-median, postero-lateral and subpostero-lateral setae to 286μ long, surface with punctae which discally form an hexagonal pattern. A single eye on each side (in the protonymph this could not be seen). Venter: as in the protonymph, the sternal shield only indicated by discontinuity of the longitudinal striations, with 3 pairs of setae;

stigma weak and with only a short peritreme. Legs as in protonymph, I 1014μ long, II 650μ, III 650μ, IV 715μ.

Remarks—This genus and species was originally erected on a single specimen, a nymph, but the precise nymphal stage was not defined. The deutonymphal stage is now described from two specimens from litter from Brookfield, Queensland, 22nd May to 2nd July, 1949 (coll. E. H. Derrick). These specimens were at first taken to be adults, but it was later realised that they were deutonymphs and that the type specimen was a protonymph. The adults are as yet unknown.

THE OCCURRENCE OF NATIVE SULPHUR AT LAKE EYRE

BY C. W. BONYTHON AND D. KING

Summary

Native sulphur in nodular form was discovered on the shore of Lake Eyre in 1951,and later the source-bed was found to be an Early-Recent clay stratigraphically positioned between Pleistocene and Late-Recent sediments.

Three exposures of sulphur nodules having distinctive characteristics were found within a radius of less than one half-mile. The nodules consist of a sulphur core in a shell of coarsely-crystalline gypsum from which crystals may project both inwards and outwards. The sulphur usually occupies only part of the interior cavity, there being an empty space between it and the bottom of the shell.

Laboratory work has shown the core material to consist of over 90 per cent. sulphur and to contain traces of arsenic and selenium, that it is crystalline, orthorhombic sulphur, and that the relative abundance of sulphur isotopes suggests an organic origin. The presence in the nodules of certain bacteria has been demonstrated by other work.

Evidence favours a theory that the gypsum crust has been formed from the core sulphur by bacterial oxidation.

The known deposit has no promise of economic development, but further occurrences can be expected to be found in the Lake Eyre region.

THE OCCURRENCE OF NATIVE SULPHUR AT LAKE EYRE

By C. W. BONYTHON* AND D. KING†

[Read 13 Oct. 1955]

SUMMARY

Native sulphur in nodular form was discovered on the shore of Lake Eyre in 1951, and later the source-bed was found to be an Early-Recent clay stratigraphically positioned between Pleistocene and Late-Recent sediments.

Three exposures of sulphur nodules having distinctive characteristics were found within a radius of less than one half-mile. The nodules consist of a sulphur core in a shell of coarsely-crystalline gypsum from which crystals may project both inwards and outwards. The sulphur usually occupies only part of the interior cavity, there being an empty space between it and the bottom of the shell.

Laboratory work has shown the core material to consist of over 90 per cent. sulphur and to contain traces of arsenic and selenium, that it is crystalline orthorhombic sulphur, and that the relative abundance of sulphur isotopes suggests an organic origin. The presence in the nodules of certain bacteria has been demonstrated by other work.

Evidence favours a theory that the gypsum crust has been formed from the core sulphur by bacterial oxidation.

The known deposit has no promise of economic development, but further occurrences can be expected to be found in the Lake Eyre region.

INTRODUCTION

Native sulphur was first found at Lake Eyre by one of us (C.W.B.) in December, 1951, on the south-eastern shore of Madigan Gulf (Bonython, 1955 (b)). Several water-eroded nodules were picked up on the beach of Sulphur Peninsula at the edge of the shrinking lake waters. The pale yellow colour of the material at once suggested sulphur, an impression soon confirmed by the flame and odour from a fragment placed in the campfire.

This is the only known sedimentary deposit of native sulphur in South Australia, with the possible exception of an unconfirmed occurrence at Dalhousie Springs, 200 miles to the north-west.

Most of the nodules collected in 1951 comprised a sulphur core in a shell of coarsely-crystalline gypsum; in some the core was traversed by septa of skeletal gypsum crystals.

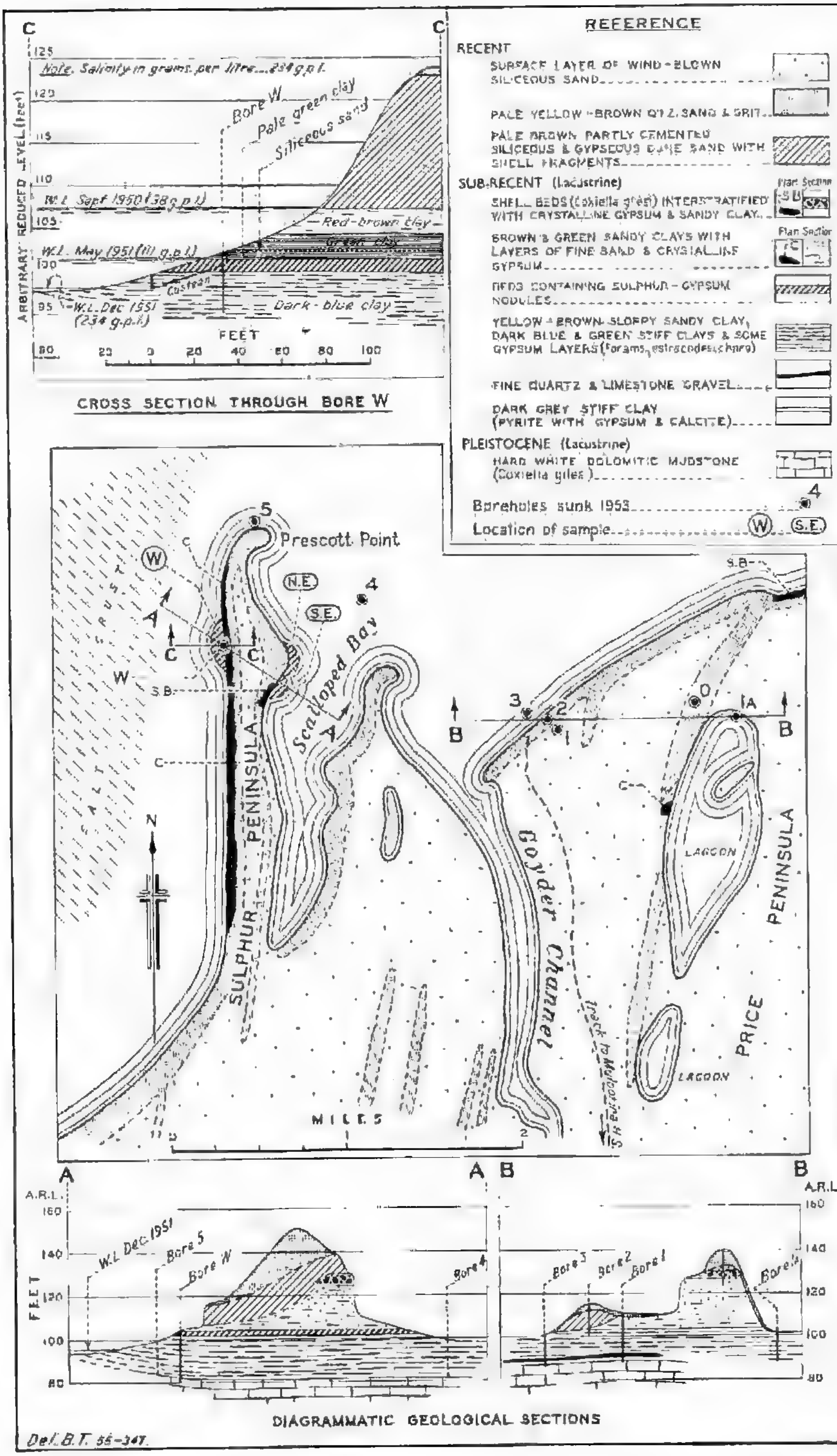
The source of the sulphur was discovered in May, 1953, when the authors journeyed together to Lake Eyre. Pieces of sulphur were then discovered *in situ* in an exposure of laminated clay outcropping at the lake shore close to the place of the 1951 find. Two other outcrops were found on the opposite side of the peninsula. These are all shown in the Locality Plan (overleaf). Plate 1, Fig. 2, shows one of the nodules found.

MODE OF OCCURRENCE

The clay bed in which the sulphur occurs is horizontally disposed and is upwards of 18 inches thick, with the sulphur nodules randomly distributed through it. It consists of alternating, varve-like laminae of finely-divided, ferruginous clay matter varying in colour from pale and dark brown to grey-green and blue. It also contains thin laminae of natural whiting (dolomitic), traces

* I.C.I. Alkali (Australia) Pty. Ltd.

† South Australian Department of Mines.



Note. Salinity in grams per litre...234 g.p.l.
Bore W
Pale green clay
Siliceous sand
W.L. Sept 1950 (38 g.p.l.)
Red-brown clay
Green clay
W.L. May 1951 (111 g.p.l.)
Costean
W.L. Dec 1951 (234 g.p.l.)
Dark-blue clay
ARBITRARY REDUCED LEVEL (feet)
FEET
CROSS SECTION THROUGH BORE W
REFERENCE
RECENT
SURFACE LAYER OF WIND-BLOWN SILICEOUS SAND
PALE YELLOW-BROWN QTZ. SAND & GRIT
PALE BROWN PARTLY CEMENTED SILICEOUS & GYPSEOUS DUNE SAND WITH SHELL FRAGMENTS
SUB-RECENT (Lacustrine)
SHELL BEDS (Coxiella gilesi) INTERSTRATIFIED WITH CRYSTALLINE GYPSUM & SANDY CLAY
BROWN & GREEN SANDY CLAYS WITH LAYERS OF FINE SAND & CRYSTALLINE GYPSUM
BEDS CONTAINING SULPHUR-GYPSUM NODULES
YELLOW-BROWN SLOPPY SANDY CLAY, DARK BLUE & GREEN STIFF CLAYS & SOME GYPSUM LAYERS (forams, ostracodes, chara)
FINE QUARTZ & LIMESTONE GRAVEL
DARK GREY STIFF CLAY (PYRITE WITH GYPSUM & CALCITE)
PLEISTOCENE (Lacustrine)
HARD WHITE DOLOMITIC MUDSTONE (Coxiella gilesi)
Boreholes sunk 1953
Location of sample
Plan Section
Prescott Point
Scalloped Bay
SULPHUR PENINSULA
SALT CRUST
Goyder Channel
PRICE PENINSULA
LAGOON
LAGOON
Track to Moolooloo H.S.
MILES
A.R.L.
W.L. Dec 1951
Bore 5
Bore W
Bore 4
Bore 3
Bore 2
Bore 1
Bore 1A
FEET
DIAGRAMMATIC GEOLOGICAL SECTIONS
Del. B.T. 55-347.

of carbonaceous matter, and disseminated crystals of gypsum and halite. Slump folding on a very small scale is common.

The sulphur-bearing clay is overlain by other clay and aeolian deposits which form the main part of Sulphur Peninsula, and the outcrops on the sloping eastern and western beaches are only narrow. Less than an acre of sulphur-bearing clay is exposed at the location on the western shore (hereafter referred to as the "western," or "W," location). The two other locations, where the bed outcrops on the eastern, or Scalloped Bay, side of the peninsula, are hereafter referred to respectively as the "north-eastern," or "NE," location and the "south-eastern," or "SE," location.

TABLE 1.

Stratigraphy of Sulphur Occurrences

Situation	Description	Thickness ft.	in.
Shoreline cliffs	Crystalline gypsum, freshwater shells (*Coxiella gilesi*) and sandy clay	6	0
	Brown, sandy clay and fine, crystalline gypsum	14	0
Beach exposure	Red-brown clay	3	0
	Interbedded green clay and crystalline gypsum	1	9
	Fine, white, siliceous sand	0	3
	Pale green clay	1	0
	Laminated, brown and grey-green clay with *sulphur-gypsum* nodules	1	6
No outcrop—bore data	Dark-blue clay	7	6
	Stiff, dark-blue clay	10	0
	Stiff, dark-green clay	3	0
	Total	48	0

THE STRATIGRAPHIC SUCCESSION

The sulphur-bearing clay forms part of a series of clay beds assigned to Early-Recent age, which overlies a Pleistocene dolomitic mudstone. The clay beds are overlain in turn by Early-Recent gypseous shell beds, and by Late-Recent aeolian deposits (King, 1955). The stratigraphy is interpreted from outcrops of the gypseous shell beds near Location SE, and from data obtained from a borehole near Location W. Table 1 is a generalized account of the Early-Recent succession in the vicinity of Sulphur Peninsula, and the Locality Plan (opposite) includes an actual vertical cross section at Location W.

THE EXAMINATION OF THE SULPHUR OCCURRENCES

The exposure at Location W was opened up by a shallow costean (see Plate 1, Fig. 1), and it was found that the nodules are present not only at the surface of the lake bed, but also at depths down to 18 inches. Those uncovered by digging are similar to the nodules found at the surface, but whereas the former are entirely encased in a crust of gypsum crystals, the latter usually have an imperfect crust permitting both the ingress of sand, clay and organic debris and also the removal by erosion of some of the sulphur core. The same is true of the NE and SE exposures.

Sulphur nodules from the three locations have certain characteristic differences:

(a) Nodules from Location W have a comparatively thin outer crust of gypsum, and the sulphur occupies most of the interior cavity. The clay in contact with the outside is usually grey-green, but in the near vicinity there are occasional mottlings or larger areas of a rusty-red colour (indicative of ferric iron). However, the clay immediately in contact with the gypsum crust is never rusty-red.

(b) Nodules from Location NE have a thicker gypsum crust, often iron-stained. The sulphur occupies a smaller proportion of the interior cavity than in (a), i.e., more of the cavity consists of empty space. At this location there are some sealed, hollow nodules of the same external appearance as the others, but containing little or no sulphur.

(c) Nodules from Location SE usually have a thicker, more massive crust than both (a) and (b) material. Some of the gypsum aggregates are over one foot across, with frequently more than one sulphur kernel embedded in the alabastrine mass. There is practically no iron staining.

Nodule shape varies from that of irregular spheroidal or ovoid masses at Location W (see Plate 2, Fig. 1) to flattish masses thinning towards the edges at Location SE (see Plate 2, Fig. 2). A tapering, down-pointing base or "root" of gypsum is characteristic of many nodules from all three locations. Nodules from Location NE show individual variations — one (see Plate 3, Fig. 1) showing the upper part in vertical cross-section to be a flattened rectangle, and another (see plate 3, Fig. 2) having an elliptical cavity; in both the core sulphur clings to the gypsum crust roof and keeps clear of the bottom (except where protruding crystals reach up to it), while in only the former case the base of the gypsum crust is thickened into a root.

It seems to be a general characteristic that the sulphur occupies the top of the cavity, and it is the more marked in the NE and SE examples. In some of the SE nodules, which have a very thick gypsum shell, the sulphur is restricted to a small, subsidiary dome in the roof of the cavity (see Plate 2, Fig. 2).

The core sulphur has plane, vertical fissures running through it in some cases, particularly that from Location W. These are commonly occupied by crystalline gypsum.

The outside of the crust consists of coarse crystals projecting outwards, while on the inside smaller, tooth-like crystals project towards the centre. The outside ones are frequently opaque and blade-like (Locations NE and SE), while those inside the cavity are well-formed, and occasionally clear, but more often containing inclusions of finely-divided sulphur which render them opaque. Growths of gypsum crystals reaching upwards from the periphery to touch the core sulphur are shown in Plate 3, Fig. 2, depicting a nodule from Location NE.

LABORATORY EXAMINATION OF THE SULPHUR

The physical state of the sulphur in the nodules was investigated by means of the microscope, the electron microscope and the X-ray powder diffraction technique. Chemical analysis was carried out, and measurements were made of the sulphur isotope abundance. Microbiological studies also were made by Baas Becking and Kaplan (1955) who identified certain sulphate-reducing and sulphur-oxidizing bacteria; this work is reported in another paper of the present volume.

Microscopic Examination:

G. H. Taylor of the South Australian Department of Mines, after making a petrological examination of one of the W nodules, reported as follows:

"The greater part of this material is native sulphur and gypsum, with up to 20 per cent. of water and water-soluble salts (as received). The sulphur occurs in cavities surrounded by crusts of well-crystallized gypsum, with which is associated an appreciable amount of a carbonate mineral, probably calcite. The water-soluble salts seem to consist chiefly of halite (NaCl)."

Examination under the Electron Microscope:

S. C. Tomlin used the electron microscope of the University of Adelaide to photograph a sample of the sulphur core material. The examination was inconclusive, because the sulphur vaporized in the heat of the electron beam before it could be photographed.

However, there was an interesting sequel in the finding of a peculiar fibrous and laminar residue when all the sulphur had evaporated (see Plate 4). It has not been identified, but it may be organic; it does not have the characteristics of a crystalline substance. (The sample had initially been repeatedly extracted with water to remove soluble impurities.)

Examination by X-ray Diffraction:

An X-ray powder diffraction pattern was measured by K. Norrish and L. Rogers of the Division of Soils, C.S.I.R.O. The core material was found to be crystalline, orthorhombic sulphur, containing possibly a trace of gypsum. Full details are given in the Appendix.

Chemical Analysis:

Sulphur core material (as free as far as possible from contamination by the gypsum shell) was gathered from all three locations and mixed so as to to provide a single, composite sample. An analysis of this sample carried out under the direction of T. R. Frost, Chief Analyst of the South Australian Department of Mines, is shown in Table 2 together with an analysis of native sulphur from Louisiana, U.S.A.*

TABLE 2.

Chemical Analysis of Sulphur.

	Lake Eyre (composite sample of sulphur as found)	Port Sulphur, Louisiana (as mined by Frasch process)
Elemental Sulphur (S)	90·9%	99·74%
Insoluble in aniline	8·3	
Ash	-	less than 0·01
Moisture	0·3	—*
Hydrocarbon	—	0·25
Arsenic	0·00007	less than 0·0002
Selenium	0·006	less than 0·00005

* Analysis expressed on dry basis.

Assuming that the fraction insoluble in aniline in the Lake Eyre material is equivalent to ash makes it less pure than the Louisiana material. However, the latter was mined by the Frasch process (injecting steam and hot water down a borehole), so the two samples are not strictly comparable in respect to ash content. Both contain traces of arsenic and selenium.

* Information supplied by D. B. Mason of the Freeport Sulphur Company, New York.

H. G. Thode, of McMaster University, Ontario, measured the relative isotopic abundance of S^{32} and S^{34} in a weathered-out nodule from Location W at Lake Eyre, his findings being as follows:

TABLE 3.
Lake Eyre Sulphur Nodule

Constituent	S^{32}/S^{34} ratio
Native sulphur	22·28
Associated sulphate	21·95**

** This determination is to be repeated, for there is some doubt as to whether the sulphate was the true gypsum crust or a coating of gypsum deposited on the nodule in question by the evaporating lake waters.

These results may be compared with other such figures derived by Thode (1951) from forms of free and combined sulphur occurring generally in nature (see Table 4).

TABLE 4.

Material	S^{32}/S^{34} ratio
Sea water sulphate	21·7-21·9
Gypsum	21·6-22·2
Native sulphur	
(a) volcanic origin	21·8-22·1
(b) organic origin	22·2-22·7

The native sulphur from Lake Eyre hence has an S^{32}/S^{34} ratio corresponding to sulphur of organic origin.

THE ORIGIN OF THE SULPHUR

Native sulphur may originate from volcanic action, or from the breakdown of naturally-occurring sulphur compounds by organic chemical agencies. There is no evidence of vulcanism at Lake Eyre, but on the other hand the sedimentary environment, the S^{32}/S^{34} ratio and the presence of both sulphates and bacteria point to an organic origin.

The physical state in which the Lake Eyre sulphur occurs will not necessarily provide a clue to the mode of formation, for it has been shown that a certain Indian sulphur of known microbiological origin was originally colloidal but had crystallized on ageing.

Microbiological Processes:

Butlin & Postgate (1954) have written of sulphur being formed by microbiological processes and they describe a two-stage process in which sulphate is first reduced to sulphide by the bacterial action of *Desulphovibrio desulphuricans,* following which the sulphide is oxidizied to elemental sulphur by the coloured, photo-synthetic, sulphur-oxidizing bacteria *Chlorobium* and *Chromatium.*

Baas-Becking and Kaplan (1955) agree that the first stage of such a process is bacterial, but they claim that under natural conditions the second stage is a simple chemical oxidation involving atmospheric oxygen and iron.

Subba Rau, Iya & Sreenivasaya (1947) have reported the occurrence of a sulphur-bearing clay near Muslipatam in India. (It has similarities to the Lake Eyre material.) Here it is claimed that the reduction is effected by flagellate vibrio, and that the oxidation is performed catalytically by atmospheric oxidation in the presence of iron.

Elemental sulphur may also be degraded to sulphate by bacterial oxidation, one of the bacteria reacting in this way being *Thiobacillus thiooxidans* (Butlin & Postgate, 1954).

Implications of the Sulphur-Gypsum Association:

It is highly significant that sulphur and gypsum are intimately associated in the Lake Eyre nodules, particularly as the concretionary form of most of the gypsum crusts is markedly different from that of the crystalline gypsum so common and widespread in Quarternary sediments of the Lake Eyre region. There are two possible interpretations of this association — the first, that the gypsum crust is a remnant of pre-existing sulphate from which the sulphur has been formed by reduction, and the second, that the gypsum crust has been formed by oxidation of pre-existing elemental sulphur of which the present sulphur core is a remnant. Both sulphate-reducing and sulphur-oxidizing bacteria are found in the nodules (Baas-Becking & Kaplan, 1955), so neither theory is to be preferred on this account.

The shape of the nodules may have significance concerning the mode of formation. The tendency of the crystals of the crust to develop both inwards and outwards, the thickened, tapering base or "root," and the separation of the base of the sulphur core from the bottom of the cavity in the gypsum crust are the principal morphological characteristics, but their interpretations are not obvious.

The Sulphate-reduction Theory of Origin:

In such a process it is implied that the reduction begins in the interior of a gypsum mass, and that the reactions spread gradually outwards. The oxidation of the sulphide must occur there also.

Evidence against this theory is the unlikelihood of gypsum existing initially in masses shaped like the present nodules, and the fact that gypsum crystals facing inwards from the shell do not generally have the corroded appearance to be expected if the gypsum was being consumed. The theory is favoured by the fact that the cavity within the gypsum shell is not completely filled by sulphur, for, as Baas-Becking & Kaplan have pointed out, the formation of elemental sulphur from gypsum is accompanied by a loss of volume. However, fuller consideration of the facts concerning the Lake Eyre occurrences will reveal the following conflict with the theory.

A nodule from Location W has a comparatively thin gypsum crust, so it may be supposed that the conversion of the original gypsum to sulphur has proceeded nearly to completion; on this basis the empty volume within the gypsum cavity should be large in relation to the space occupied by the sulphur. This is not so — the proportion of empty volume is small. Conversely, a nodule from Locations NE and SE has a thick gypsum crust, and so the proportion of empty volume within should be small. In fact, the proportion of empty volume is large in the NE and SE nodules.

The isotope abundance determinations of Thode (see Table 3) show a slightly smaller proportion of the S^{34} isotope in the sulphur than in the associated sulphate, and if this be interpreted as the "fractionation" described by Thode occurring during the microbiological reduction of sulphate then the theory is supported.

The Sulphur-Oxidation Theory of Origin:

This supposes (Baas-Becking & Kaplan, 1955) that the gypsum crust was formed by reaction between HSO_4^- ions, which resulted from the action of *thiooxidans* bacillus on pre-existing elemental sulphur, and Ca^{++} from the surrounding clay. In this case the gypsum crust would presumably have grown by accretion outside the sulphur core. The form of the nodular gypsum is in agreement with such a mode of formation, as also is the presence of occluded sulphur in gypsum crystals, and the attitude of the crystals of the crust in appearing to have grown outwards from the main shell, as well as inwards to a lesser extent. The argument involving the proportions of the cavity volume occupied by sulphur and by empty space introduces no conflict with the sulphur-oxidation theory, but supports the view that the gypsum crust was formed from pre-existing sulphur.

Origin Involving Organic Remains:

One of us (D.K.) is impressed by the fact that the presence of decomposable organic matter is a condition favouring certain of the bacterial processes cited by Butlin & Postgate and believes that the past existence of decaying fish remains might not only have supported the formation of sulphur by bacterial action, but would account also for the concentration of the sulphur substance in discrete and sporadically distributed masses. Subsequent bacterial action could have made these aggregations of sulphur revert partly to gypsum.

Concluding Discussion on Origin:

It is certain that the Lake Eyre sulphur is of organic origin. The weight of evidence on the origin of the gypsum crust favours its having been formed subsequently from part of the sulphur by bacterial oxidation.

The sulphur was probably formed* prior to or during the sedimentation of the clay bed in which it now occurs, but it is also possible that it was formed subsequently *in situ*. The latter process, if it occurred, presumably would have been favoured in those parts of the clay bed outcropping on either side of the peninsula because there the lake waters and the atmosphere would have had effective access to it. The position of the present sulphur-bearing bed in relation to the level of lake waters may be significant, for bacterial reactions (like those studied by Butlin & Postgate in Cyrenaica) possibly take place more readily in a brine medium than in the dry state. Fig. 1 shows the respective levels in terms of an arbitrary datum (Bonython, 1955 (a)), and the salinity of the lake waters when at certain levels. (Expressed as gm. NaCl per litre.) The bed was submerged 6 ft. below the lake surface during the great flooding of 1949-50, but it is unlikely to be reached often by the waters during the minor floodings that under average circumstances may occur at intervals of the order of five years.

It would be instructive to find out if the sulphur nodules also occur in those parts of the bed deeply buried beneath the sediments of the Sulphur Peninsula ridge. This would be ascertained by sinking bores to intersect the bed in that area.

THE ECONOMIC POSSIBILITIES

The known sulphur occurrences occupy a total area of approximately one acre, and in this area the sulphur content of the bed as a whole would be considerably less than one per cent. A deposit of this size and grade has no value in itself, but as the sulphur is found within a definite stratigraphic horizon that was probably laid down under quiet, lacustrine conditions — and for this reason could be expected to extend laterally for many miles in the Lake Eyre

* As this paper goes to press Baas-Becking and Kaplan report a Carbon-14 determination placing the age at $19{,}100 \pm 500$ years.

Basin — some further exploratory work is necessary before the potentialities can be accurately assessed.

In the locality examined the sulphur-bearing clays are horizontal and slightly higher in elevation than the lake bed, and testing would involve the sinking of boreholes or pits on the mainland adjacent to the lake margin. There is also the possibility that there may be a repetition of sulphur deposits at greater depths, and in investigating this a borehole might by sunk as deep as the upper limits of the underlying Mesozoic formations.

ACKNOWLEDGMENT

The authors acknowledge the help given in the field by Mr. W. G. Fenner and Mr. A. D. P. Dyer, and also by A. C. I. Adams and J. R. Bryan — boys of St. Peter's College, Adelaide. For undertaking investigations of the sulphur in the laboratory they wish to thank Prof. H. G. Thode, F.R.S., of McMaster University, Ontario, Canada; Dr. S. G. Tomlin of the Department of Physics, University of Adelaide; Dr. K. Norrish and Mrs. L. Rogers of the Division of Soils, C.S.I.R.O.; and Mr. T. W. Dalwood of the South Australian Department of Mines. Fig. 1 and Plates 2 and 3 were prepared by Messrs. B. Thomas and G. P. King.

Thanks are due to Mr. S. B. Dickinson, Director of Mines, South Australia, for making it possible for one of the authors (D.K.) to visit Lake Eyre to carry out this work.

REFERENCES

Baas-Becking, L. G. M., and Kaplan, I. R., 1955. The Microbiological Origin of the Sulphur Nodules of Lake Eyre. (In this volume.)

Bonython, C. W., 1955. Lake Eyre, South Australia — The Great Flooding of 1949-50, Roy. Geogr. Soc. A/sia, S. Aust. Branch, Adelaide. (a) The Filling and Drying-up, pp. 27-36; (b) Flora, Fauna and Minerals from Lake Eyre and Surroundings, pp. 71-75.

Butlin, K. R., and Postgate, J. R., 1954. The Microbiological Formation of Sulphur in Cyrenaican Lakes — The Biology of Deserts, 112-122, London, Inst. Biol.

King, D., 1955. The Quaternary Stratigraphic Record at Lake Eyre North and the Evolution of Existing Topographic Forms. (In this volume.)

Subba Rao, M. S., Iya, K. K., and Sreenivasaya, M., 1947. Proc. 4th Int. Congr. Microbiol., 494.

Thode, H. G., 1951. Research (Research Correspondence) 4: 582-3.

APPENDIX

X-ray Powder Diffraction Data for Lake Eyre Sulphur.

1		2		1		2	
dÅ	I/I_1	dÅ	I/I_1	dÅ	I/I_1	dÅ	I/I_1
7·7*	20					2·19	20
5·66	40	5·57	60	2·10	70	2·08	70
4·01	30	3·94	70	1·99	10		
3·84	100	3·74	100	1·95	<5		
3·54	5	3·53	50	1·89	70	1·88	70
3·42	70	3·38	60	1·82	20	1·81	50
3·30	40	3·26	20	1·77	80	1·76	70
3·19	90	3·15	90	1·75	40		
3·08	40	3·04	70	1·72	80	1·71	60
2·82	40	2·79	60	1·69	70	1·68	50
		2·67	20	1·65	40	1·64	50
2·60	30	2·59	50	1·62	70		
2·56	5			1·60	70	1·60	60d
2·47	40	2·46	20	1·43	20	1·43	50
2·41	40	2·40	20	1·41	70	1·41	60
2·35	40	2·34	20			1·38	20
2·27	20	2·26	20	1·35	20	1·35	70

d = doublet.

1. Native Sulphur from Lake Eyre [5·73 cm. diameter camera: Co radiation, Fe filtered (λ = 1·7899 Å); I/I_1 estimated by eye].

2. After data given for orthorhombic sulphur by A.S.T.M. Crystallographic Index [Cu radiation, Al filtered (λ = 1·541 Å)]. The Cu K_{β} lines given by the index have not been included.

* This line may be due to gypsum which is a possible impurity.

Fig. 1.—The costean at Location W, showing (left) the rod being withdrawn from the bore.

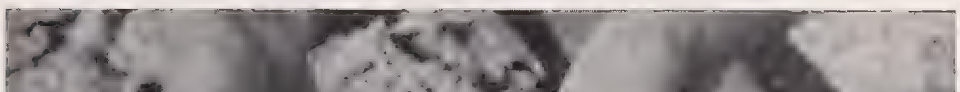


Fig. 2.—Broken sulphur nodule freshly dug at Location W.

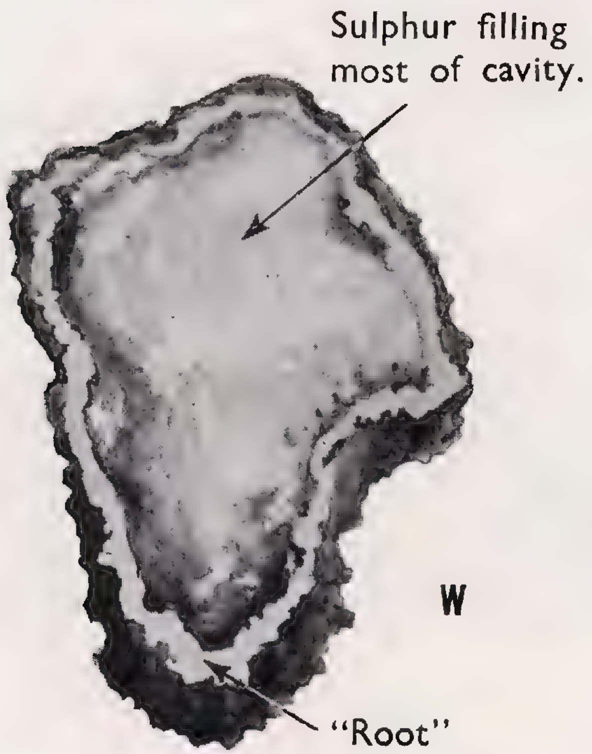


Fig. 1.–Sectioned nodule from Location W (4/5 natural size).

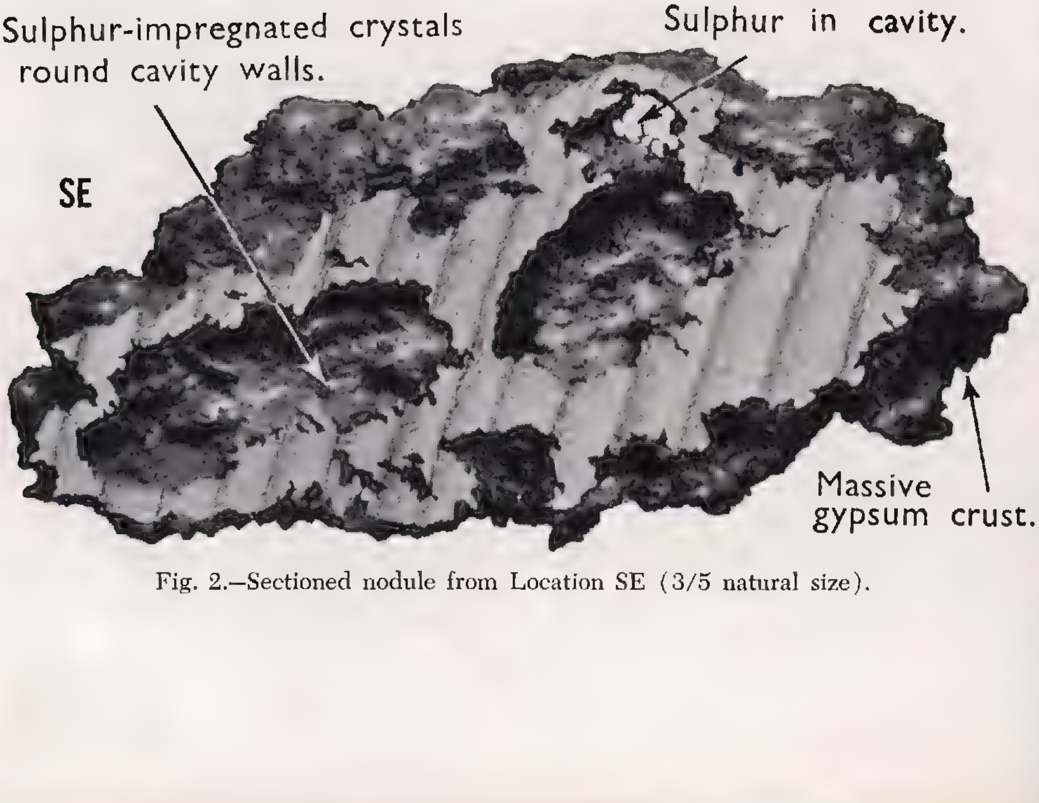


Fig. 2.–Sectioned nodule from Location SE (3/5 natural size).

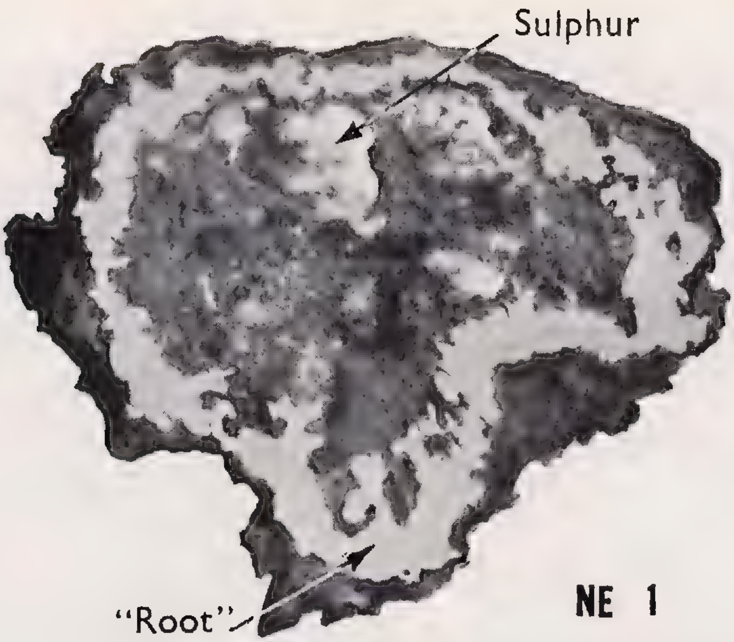


Fig. 1.–Sectioned nodule from Location NE (4/5 natural size).

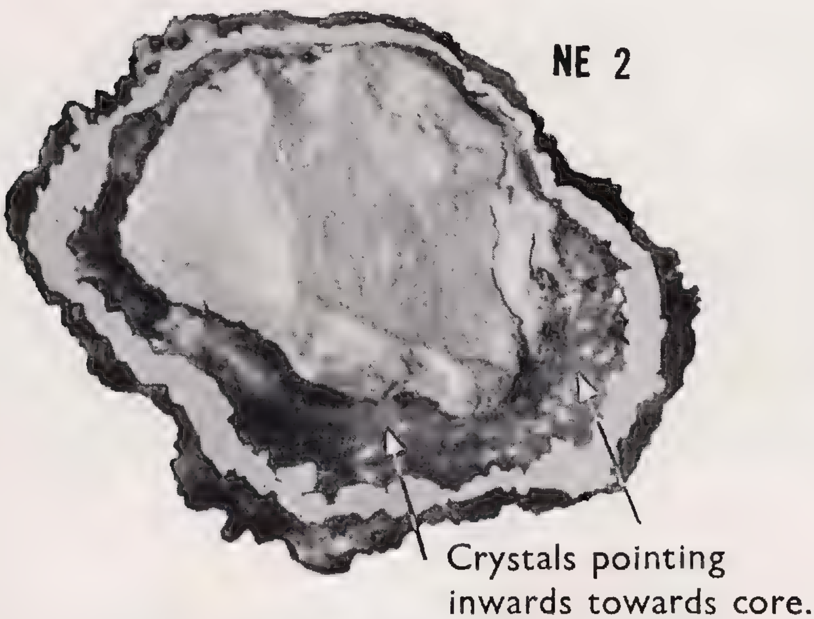


Fig. 2.–Sectioned nodule from Location NE (4/5 natural size). Core has fractured surface approximately in plane of section.

Electron micrograph (12,000 x) of unknown residue after evaporation of the sulphur.

THE OCCURRENCE OF GRANITE TILLITE AND GRANITE GNEISS TILLITE AT POOLAMACCA, BROKEN HILL, N.S.W.

BY D. R. BOWES

Summary

A study has been made of some unusual coarse fragmental rock types occurring in the vicinity of Poolamacca. These rocks form part of the basal beds of the Torrowangee Series which rests unconformably on rocks of the Willyama Complex around the margins of the Poolamacca Inlier. They consist essentially of boulders and fine detritus derived directly from the immediately underlying rocks by the action of land ice. Granite and granite gneiss are overlain by granite tillite and granite gneiss tillite respectively while a rock containing boulders of granite and granite gneiss overlies a granite-granite gneiss contact.

Details of the field occurrence, petrography and chemical composition of the various rock types are set out and the occurrences of comparable rocks in other parts of the Broken Hill area are given.

THE OCCURRENCE OF GRANITE TILLITE AND GRANITE GNEISS TILLITE AT POOLAMACCA, BROKEN HILL, N.S.W.

By D. R. Bowes*

(*Communicated by A. W. Kleeman*)

[Read 13 Oct. 1955]

SUMMARY

A study has been made of some unusual coarse fragmental rock types occurring in the vicinity of Poolamacca. These rocks form part of the basal beds of the Torrowangee Series which rests unconformably on rocks of the Willyama Complex around the margins of the Poolamacca Inlier. They consist essentially of boulders and fine detritus derived directly from the immediately underlying rocks by the action of land ice. Granite and granite gneiss are overlain by granite tillite and granite gneiss tillite respectively while a rock containing boulders of granite and granite gneiss overlies a granite-granite gneiss contact.

Details of the field occurrence, petrography and chemical composition of the various rock types are set out and the occurrences of comparable rocks in other parts of the Broken Hill area are given.

I. INTRODUCTION

A. Location

Poolamacca Head Station is situated thirty-two miles north of Broken Hill in the Northern Barrier Ranges with the approximate position of latitude 31° 30′ S., longitude 141° 28′ E. (Fig. 1). The name of the Head Station is given to the inlier of Willyama rocks which outcrop immediately to the north (Andrews, 1922, p. 116). Rocks of the Torrowangee Series surround the Poolamacca Inlier (*vide* King and Thomson, 1953, Fig. 11). The topography consists of low hills covered by sparse vegetation. A semi-arid climate prevails and outcrops are abundant. However, surface weathering extends to a considerable depth in parts.

B. Previous Investigations

Andrews (*op. cit.*) described "a thin discontinuous layer of granite waste, cemented with tillite material" (p. 66) cropping out near Poolamacca H.S. This rock covered part of the granite of the inlier and it was suggested that the granite "formed part of the old surface on which the later glacial deposits were laid" (p. 347). Also described was a "remarkable variant of the tillite" (p. 67) cropping out three miles south-east of Poolamacca H.S. in which ellipsoidal boulders of granite and pegmatite arranged almost end to end gave the appearance of an igneous intrusion.

King and Thomson (*op. cit.*) considered that the granite masses of the Northern Barrier Ranges (Fig. 1) were intruded during post-Torrowangee movements and occurred in the Willyama rocks just below the Willyama-Torrowangee unconformity. Granitization and pegmatization of the Torrowangee tillite at the time of the introduction of the granite was postulated as an explanation of the genesis of rocks similar to those described by Andrews (*op. cit.*) as "granite

* Department of Geology, University College of Swansea.

waste". A distant source is suggested for most of the tillite boulders, including the granitic ones. Some boulders, however, are considered of local derivation such as those near Gairdner's Tank, where the "tillite is crowded with boulders of the underlying granite gneiss" (p. 518).

Leslie and White (1955) interpreted the exposures at the northern end of the Brewery Creek Pluton as showing a granite tillite consisting almost entirely of granite boulders in an arkosic matrix resting on the eroded surface of the granite which was thus of pre-Torrowangee age. Basal beds in other parts containing much material from the immediately underlying rock are also described.

C. Present Investigations

The present investigations were initiated in 1951 from the University of Adelaide following discussions with members of the geological staff of Zinc Corporation Limited, Broken Hill, who had carried out the regional geological

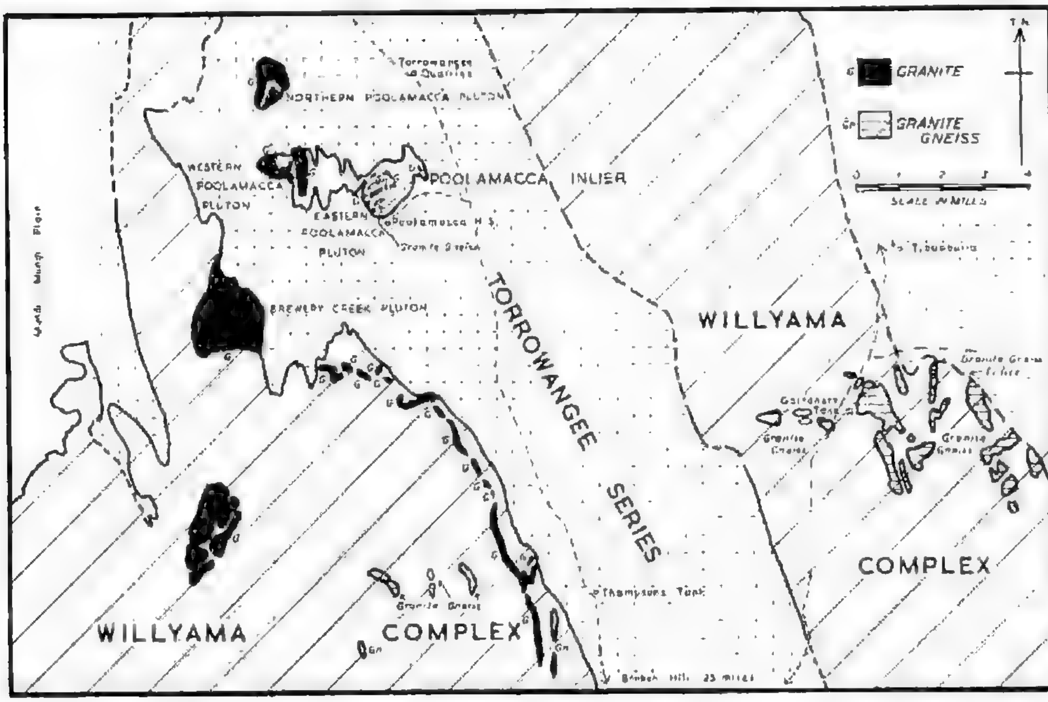


Fig. 1.—Map of the Northern Barrier Ranges (after King and Thomson (1953)) showing the principal outcrops of granite and granite gneiss.

survey of the Barrier Ranges, the results of which were published by King and Thomson (*op. cit.*). The aim of the present work was to elucidate the metamorphic and igneous history of part of the Northern Barrier Ranges, and, in particular, the genesis of the granitic and pegmatitic rocks of the area. More than sixteen square miles were mapped at the scale of 1 inch = 1,000 feet, covering the Willyama rocks of the Poolamacca Inlier and the surrounding Torrowangee rocks. Critical areas were surveyed at the scale of 1 inch = 50 feet. Field work was carried out at intervals during 1951-52 and laboratory work from 1953 onwards has been done at the University College of Swansea. The investigation of the area immediately to the south (Leslie and White, *op. cit.*) was carried out in conjunction with the present investigations.

This paper deals with (1) the granite and granite gneiss of the Willyama Complex occurring in the Poolamacca Inlier, and (2) the basal, fragmental.

glacigene sediments (granite tillite and granite gneiss tillite) of the Torrowangee Series which unconformably overlie the corresponding Willyama parent rocks. Details of field occurrence together with mineralogical and chemical composition are set out and the significance of the various rocks is discussed.

The structural and petrological history of the Willyama rocks of the Poolamacca Inlier and of the surrounding Torrowangee rocks will be discussed in later papers.

II. THE GRANITE

A. Naming and Correlation

Of the five large granite masses in the Northern Barrier Ranges recorded by King and Thomson (*op. cit.* p. 543) only the one cut by the Brewery Creek is specifically named. The presence of another granite at Poolamacca was recorded by Andrews (*op. cit.* p. 66), but it was not specifically named. For the sake of clarity in this paper, it is desirable that each granite mass should be named to enable reference to be made to it without confusion.

In the absence of prominent landmarks and creeks associated with the granites in the vicinity of Poolamacca, it is suggested that (1) the granite in the eastern part of the Poolamacca Inlier be termed the Eastern Poolamacca Pluton,* (2) the granite at the western end of the Poolamacca Inlier be termed the Western Poolamacca Pluton (previously referred to as the "western boss"), and (3) the granite one and a half miles north of the Western Poolamacca Pluton be termed the Northern Poolamacca Pluton (previously the "northern boss"). These names have been used in Fig. 1 and are used throughout this paper.

The correlation of the granites of the area with other granites in the Barrier Ranges has been discussed by King and Thomson (*op. cit.*) and Leslie and White (*op. cit.*), the latter of whom postulate for them a Middle Precambrian age.

B. Field Occurrence

(i) *Eastern Poolamacca Pluton* (Fig. 2).—Tors, which are stained yellow to brown and which weather by exfoliation, together with large, gently curved yellowish-brown exfoliate surfaces of granite crop out on the western slopes of the low hill a quarter of a mile W.N.W. of Poolamacca H.S. Further N.W. in the banks of Campbell's Creek, the granite is light grey in colour and found as irregular shaped tors. Large, curved, light grey exfoliate surfaces and small tors of granite crop out two-thirds of a mile north of Poolamacca H.S. on the low ground in the large bow of Campbell's Creek. Here the granite shows cross-cutting and intrusive relations to the granite gneiss. Granite also crops out as small masses in other parts of the eastern portion of the Poolamacca Inlier.

(ii) *Western Poolamacca Pluton* (Fig. 3).—In the creeks the granite crops out as large, gently curved, light grey coloured surfaces, whereas on the higher ground of the main part of the pluton, tors and blocks of iron-stained granite prevail. (Plate 1, Fig. 3.) The granite, which covers a considerably larger surface area than the Eastern Poolamacca Pluton, cross-cuts and intrudes low-grade schists of the Willyama Complex. Many large and small roof pendants and xenoliths are associated with the granite mass.

C. Petrography and Chemical Composition

The granite of both Eastern and Western Poolamacca Plutons is leucocratic and rich in muscovite. The grain size is generally 2-3 mm. and the texture hypidiomorphic, although many of the crystals, especially the quartz crystals, show considerable cracking and some peripheral granulation (Fig. 4a).

* Pluton is used to describe a coarse-grained igneous mass of irregular form.

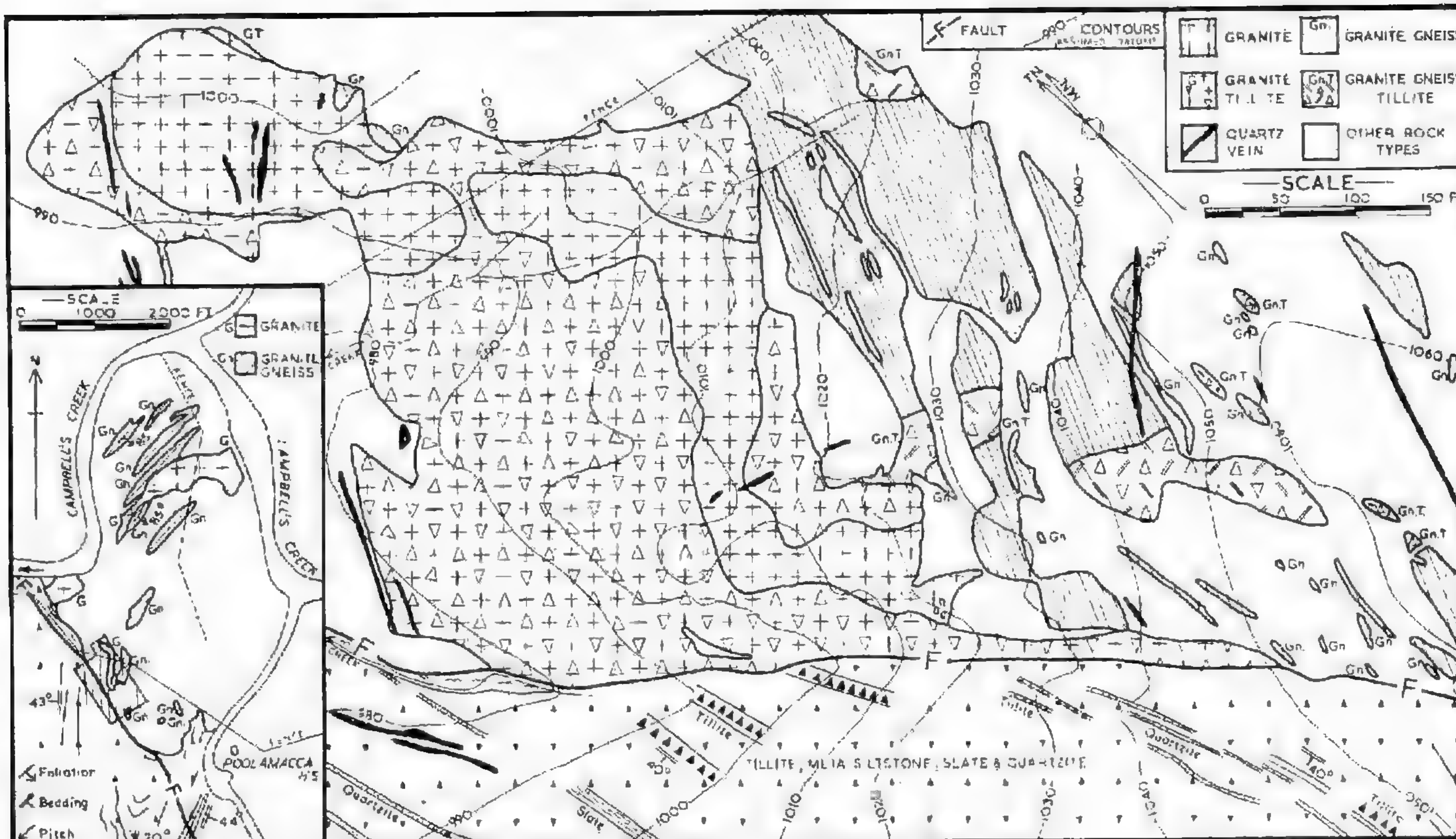


Fig. 2.—Geological map of part of the western slopes of the low hill a quarter of a mile W.N.W. of Poolamacca H.S. *Inset*—Map of the area near Poolamacca H.S. showing the principal outcrops of granite and granite gneiss.

Felspar is the most abundant constituent with plagioclase generally in excess of microcline. The plagioclase, which is subhedral in form and albite in composition, shows considerable alteration in parts and contains many inclusions, notably large flakes of muscovite. Microcline also has subhedral form and shows cross-hatching which is well developed in some crystals and poorly developed in others. Quartz, which is abundant, shows undulose extinction, much cracking and some granulation.

Muscovite is the dominant mica present with biotite only in subsidiary amounts and showing some chloritization. The accessory minerals are zircon, apatite, magnetite and tourmaline.

The chemical analysis of this rock is given in Table 1, column 1, and a comparison with the composition of the associated granites to the south of Poolamacca (Table 1, columns 7 and 8) shows the marked similarity which exists. This similarity is further borne out by the mineralogical composition and texture. Leslie and White (*op. cit.*) have indicated that these rocks compare closely with the alaskites of Johannsen (1932).

III. THE GRANITE TILLITE

A. Field Occurrence

(i) *Overlying the Eastern Poolamacca Pluton* (Fig. 2).—Resting directly on the granite of the Eastern Poolamacca Pluton is a rock composed dominantly of granite boulders which appear to be petrographically identical with the granite on which they rest. This rock was described as "granite waste" by Andrews (*op. cit.*, p. 66), but here is termed granite tillite as it is at the base of a series of sediments of glacial origin (Mawson, 1912), which form the lowest members of the Torrowangee Series in this area. The granite tillite appears, in parts, to rest in hollows in the old erosion surface, although it seems likely that the whole granite mass was covered by this rock type. No stratification is visible, this being in marked contrast with the higher parts of the series with its interbedded siltstones, quartzites, marbles and tillites (Plate 1, Figs. 1 and 2). However, the boundary between granite and granite tillite can be marked with precision.

On the western slope of the low hill a quarter of a mile W.N.W. of Poolamacca H.S., the outcrops of granite tillite look like granite outcrops. They are yellow-brown in colour and form low knobs, with smooth, curved surfaces which weather by exfoliation (Plate 1, Fig. 1). Nearby the granite tillite crops out as tors and rounded blocks (Plate 1, Fig. 2), which also weather by exfoliation. When the hardened surface of a tor is broken, the inside is often seen to be very severely weathered. In many parts the granite tillite is almost indistinguishable from the granite on the weathered face, although it sometimes has the appearance of a granite which has been severely fractured. Only on the freshly broken surface is the fragmental sedimentary nature clearly seen.

There is no apparent topographic feature along the granite-granite tillite unconformity and both rocks weather in exactly the same way. The unconformity can be mapped through tors which consist of both rock types and across a smooth, gently curved, exfoliate surface.

The granite tillite resting on the granitic mass in the banks of Campbell's Creek is light grey in colour and consists of light grey granite boulders, generally 1-3 inches across, in a slightly darker grey matrix. The unconformity surface is not planar but undulating.

(ii) *Overlying the Western Poolamacca Pluton* (Fig. 3).—The rock directly overlying the Western Poolamacca Pluton along its north-western boundary is a granite tillite composed of large, angular and sub-angular blocks of light grey

granite, up to 18 inches across, set in a darker grey quartzo-felspathic matrix (Plate 1, Fig. 4). The unconformable junction dips north-westward at approximately 30°, but the granite tillite shows no apparent signs of stratification. A lens of quartzose grit is stratigraphically above the granite tillite for the most part and there is a straightforward upward succession from unstratified granite tillite to bedded (including current bedded) grit, siltstone and tillite. This tillite is similar to that described by Mawson (1912) and others in the Torrowangee Series of other parts of the Barrier Ranges. This suggests that the granite tillite resulted from the action of local land ice, whereas the stratification in the beds above suggests deposition under water. This latter is confirmed by the presence of current bedding in the grits.

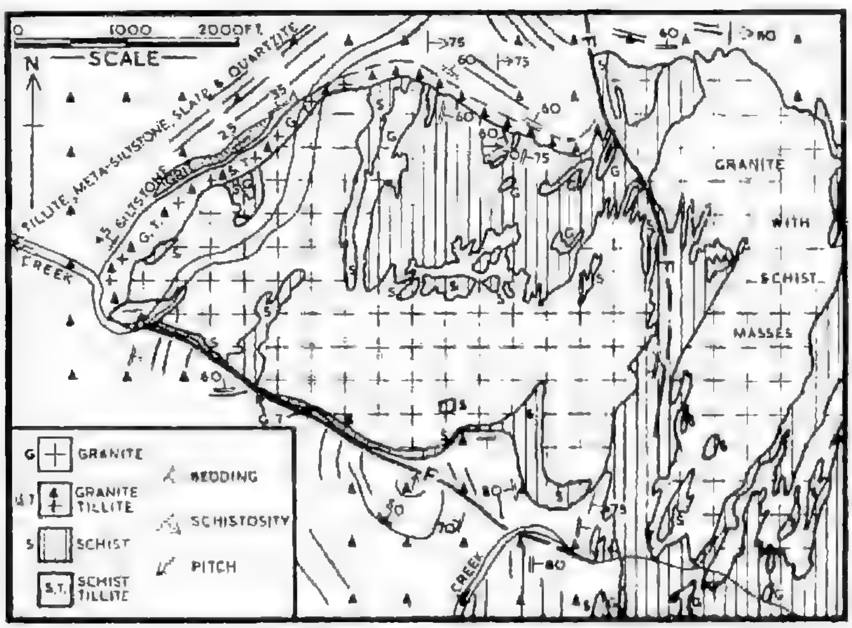


Fig. 3.—Geological map of the Western Poolamacca Pluton and surrounding area.

Where roof pendants or large xenoliths of Willyama schist form the ancient erosion surface, the overlying rock is crowded with schist boulders. This "schist tillite" changes quickly to granite tillite when the underlying schist-granite contact is passed over, although there is usually a gradational rock type in which both granite and schist boulders are present.

Granite tillite also crops out in parts along the south-western margin of the pluton. The granite boulders are generally only ½-1 inch across and the outcrops are not large because of a N.W-S.E. vertical fault which throws the granite and schist of the Willyama against the folded Torrowangee tillites, siltstones and quartzites (Fig. 3).

(iii) *In Areas Adjacent to Poolamacca.*—The occurrence of granite tillite overlying the granite of the Brewery Creek Pluton has been described by Leslie and White (*op. cit.*). Rocks resembling granite tillite have also been seen next to the granite of the Northern Poolamacca Pluton and next to the Paps Granite a mile and a half west of Thompson's Tank (Fig. 1), but further detailed investigations in these areas are required.

Lines of large granite boulders are found in parts of the tillite south of Poolamacca. The superficial appearance of a granite dyke is given, especially

where the tillite matrix is poorly exposed, but detailed investigation reveals their sedimentary origin.

B. Petrography and Chemical Composition

The granite tillite consists of sub-angular and semi-rounded granite boulders of various sizes in a matrix of mineral grains derived from the granite (Fig. 4b). The proportion of rock fragments to matrix varies considerably from place to place. In parts they make up as much as 95 per cent. of the rock, but in other parts the proportion is much lower (Plate 1, Fig. 4). The texture of the granite of the boulders is comparable with that of the granite of the Eastern and Western Poolamacca Plutons; the same is the case with the mineral proportions, compositions and inclusions.

Of the individual grains, which are angular and show no trace of crystal form, quartz is most abundant. It shows marked undulose extinction and considerable cracking as does the quartz in the granite. Fragments of microcline and plagioclase (albite) are present with the latter containing prominent muscovite inclusions. Detrital muscovite flakes, some of which are bent, are present. The fine-grained matrix consists of fragments of quartz, albite, microcline, muscovite and biotite as well as zircon, apatite and tourmaline. Authigenic sericite is also common in the matrix.

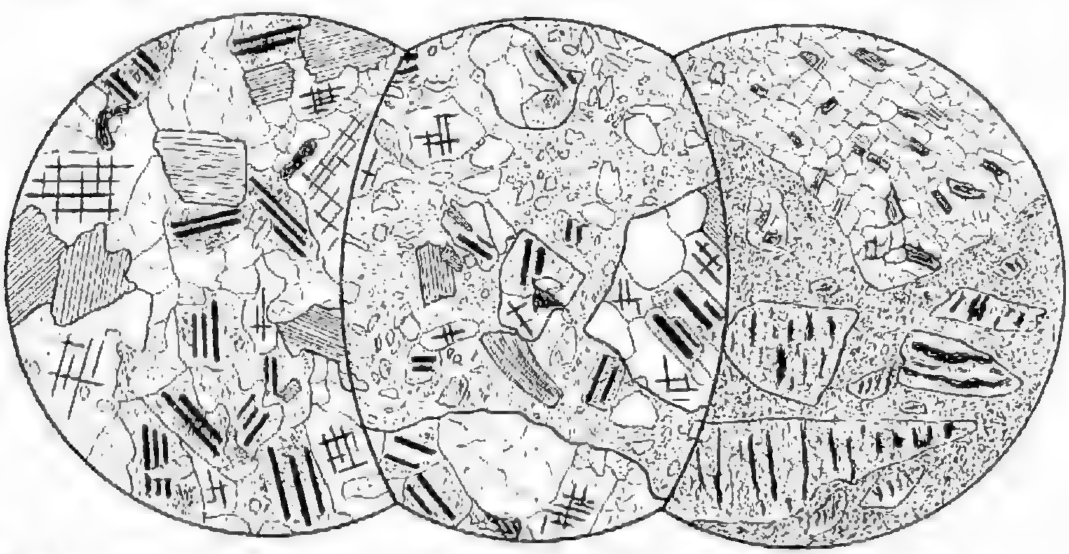


Fig. 4.—(a) Granite x 7. (b) Granite tillite x 7. (c) Tillite with granite and granite gneiss boulders x 1. These three rocks occur in the area shown in Fig. 2.

A chemical analysis of granite tillite near Poolamacca H.S. is given in Table 1, column 2. A comparison of this analysis with that of the granite of the Eastern Poolamacca Pluton and with other granites in adjacent areas (see Table 1) indicates the remarkable similarity in chemical composition of this fragmental rock and the rock from which it was derived. However, the silica and alkali proportions in particular indicate that the matrix is slightly richer in quartz and poorer in felspar and muscovite compared with the parent granite.

IV. THE GRANITE GNEISS

A. Field Occurrence

This rock type, which is of extensive outcrop but of variable composition and texture in the Barrier Ranges (Andrews *op. cit.*, King and Thom-

son *op. cit.*), crops out in the eastern part of the Poolamacca Inlier. Good outcrops occur on the low hill a quarter of a mile W.N.W. of Poolamacca H.S. and to the north in the large bow in Campbell's Creek (Fig. 2). The rock is light coloured, quartzo-felspathic and often yellow-brown on the weathered surface. Unlike the granite, it tends to break into angular blocks. Biotite flakes,

TABLE 1.

	1	2	3	4	5	6	7	8
SiO_2	73·3	76·9	73·2	73·2	72·2	70·0	73·08	74·07
TiO_2	0·18	0·14	0·40	0·34	0·34	0·56	0·24	0·19
Al_2O_3	14·4	12·4	13·0	14·1	14·5	12·6	14·78	14·77
Fe_2O_3	0·66	0·53	0·51	1·4	1·4	0·01	0·67	0·51
FeO	0·66	1·0	2·9	1·5	1·5	3·1	0·79	0·46
MnO	0·01	0·02	0·23	0·06	0·06	0·06	0·01	0·01
MgO	0·44	0·54	1·2	0·89	0·85	3·6	0·28	0·16
CaO	0·47	0·34	0·73	0·51	0·49	3·0	0·55	0·51
Na_2O	4·0	2·8	4·2	4·9	5·3	1·4	4·35	3·89
K_2O	5·4	4·7	3·2	2·7	2·7	3·4	4·17	4·43
H_2O+	0·67	0·57	0·63	0·55	0·76	1·0	0·77	0·70
H_2O	—	—	—	—	—	—	0·21	0·15
CO_2	—	—	—	—	—	1·6*	—	—
P_2O_5	0·23	0·18	0·14	0·15	0·14	0·12	0·11	0·10
BaO	—	—	—	—	—	—	0·02	—
ZrO_2	—	—				—	0·01	0·03
S	—	—	—		—	—		0·03
TOTAL	100·4	100·1	100·3	100·3	100·2	100·5	100·07	100·01

* From loss on ignition.

1. Granite; 600 yards W.N.W. of Poolamacca H.S., Barrier Ranges, N.S.W. Analyst: D. R. Bowes.
2. Granite tillite; 600 yards W.N.W. of Poolamacca H.S., Barrier Ranges, N.S.W. Analyst: D. R. Bowes.
3. Granite gneiss; 400 yards W.N.W. of Poolamacca H.S., Barrier Ranges, N.S.W. Analyst: D. R. Bowes.
4. Granite gneiss boulder in granite gneiss tillite; 400 yards W.N.W. of Poolamacca H.S., Barrier Ranges, N.S.W. Analyst: D. R. Bowes.
5. Granite gneiss tillite; 400 yards W.N.W. of Poolamacca H.S., Barrier Ranges, N.S.W. Analyst: D. R. Bowes.
6. Tillite; 600 yards W. of Poolamacca H.S., Barrier Ranges, N.S.W. Analyst: D. R. Bowes.
7. Granite from Wookookarro Creek, S. of Poolamacca, Barrier Ranges, N.S.W. Analyst: A. J. R. White (Leslie & White *op. cit.*)
8. Brewery Creek Granite, Poolamacca, Barrier Ranges, N.S.W. Analyst: R. B. Leslie (Leslie & White *op. cit.*)

rarely exceeding 20 per cent. and generally making up about 10 per cent. of the rock, show parallel alignment and impart a distinct foliation to the rock (Fig. 5a). This internal banding is considered by King and Thomson (*op. cit.*) as relict from original bedding after the formation of the granite gneiss by granitization of sediments.

The granite of the Eastern Poolamacca Pluton post-dates the granite gneiss which it cross-cuts and intrudes.

B. Petrography and Chemical Composition

The granite gneiss is a completely recrystallized rock with an average grain size of about 1 mm. Some of the biotite flakes are up to 3 mm. in their longest direction. The rock is made up chiefly of quartz and felspar which show sutured interlocking boundaries. Quartz, the most abundant mineral, shows cracking, while both plagioclase (oligoclase) and microcline are present in considerable proportions. The majority of biotite flakes, which are chloritized in parts, show alignment (Fig. 5a) and some muscovite flakes are associated with the biotite. In parts the rock is patchy with some areas more quartz- or felspar-rich than others. Sphene, zircon and magnetite are accessory minerals.

A chemical analysis of granite gneiss from near Poolamacca H.S. and an analysis of a granite gneiss boulder in the overlying beds are given in Table 1, columns 3 and 4. The analyses indicate the essentially granitic composition of these rocks.

V. THE GRANITE GNEISS TILLITE

A. Field Occurrence

(i) *Near Poolamacca H.S.* (Fig. 2).—Resting directly on the granite gneiss of the Willyama Inlier is a rock composed essentially of angular boulders of granite gneiss which appear to be petrographically identical with the underlying rock. This fragmental sedimentary rock is similar in field occurrence to that of the granite tillite and it bears the same relationship to the granite gneiss as the granite tillite does to the granite. It is thus termed a granite gneiss tillite.

Exposures of this rock crop out on the eastern slopes, the top, and the western slopes of the low hill a quarter of a mile W.N.W. of Poolamacca H.S. The boundary between the granite gneiss tillite and the underlying granite gneiss is sharp and clearly discernible. Stratification is not obvious in the rock itself, which has the appearance of being a mass of granite gneiss detritus. The angular shape of the boulders and the random orientation of the foliation planes in the various fragments emphasize the fragmental nature of the rock (Fig. 5c). Most of the weathered surfaces are yellowish-brown similar to that of the underlying granite gneiss.

One exposure revealed a rock which contained both granite gneiss and granite boulders (Fig. 4c). This was situated stratigraphically above a granite gneiss-granite contact and indicated the existence of a transition from granite gneiss tillite to granite tillite sympathetic with the change in the underlying parent rock. This transition appears to be a rapid one.

(ii) *In Areas Adjacent to Poolamacca.*—King and Thomson (*op. cit.*) described the occurrence of granite gneiss tillite near Gairdner's Tank (Fig. 1). Here the Willyama rock type is a granitic augen gneiss and the overlying basal Torrowangee rock is crowded with boulders of this rock type.

B. Petrography and Chemical Composition

Angular and sub-angular fragments of granite gneiss from six inches across down to the size of two or three crystals, make up as much as 90 per cent. of the rock in some parts. However, they generally contribute about 75 per cent., the remainder being a fine-grained, fragmental matrix (Fig. 5b). The mineral compositions and proportions and the rock texture of the boulders are similar to those of the underlying granite gneiss. Some of these rocks consist of a mass of cracked and partly disintegrated rock fragments, and in these cases it is often impossible to distinguish rock fragments from the matrix.

The matrix consists essentially of angular fragments of quartz, oligoclase, microcline and biotite of similar grain size to that of the parent rock. Between these fragments is finer-grained detritus—quartz, oligoclase, microcline, biotite,

muscovite and magnetite together with authigenic sericite. In parts of the matrix quartz fragments predominate, while in other parts felspar is the dominant mineral.

Analyses of (1) granite gneiss of the Willyama Complex, (2) a boulder from the granite gneiss tillite, and (3) the granite gneiss tillite from which the boulder was taken, are set out in Table 1, columns 3, 4 and 5. The latter two rocks are distinctly iron stained and this accounts for the proportions of ferrous and ferric iron compared with those of the granite gneiss from the Willyama Complex. Apart from this, the chemical composition of all three rocks is remarkably similar. In particular the correspondence between the boulder of granite gneiss and the granite gneiss itself is striking and lends support to the postulated origin of these coarse fragmental rocks.

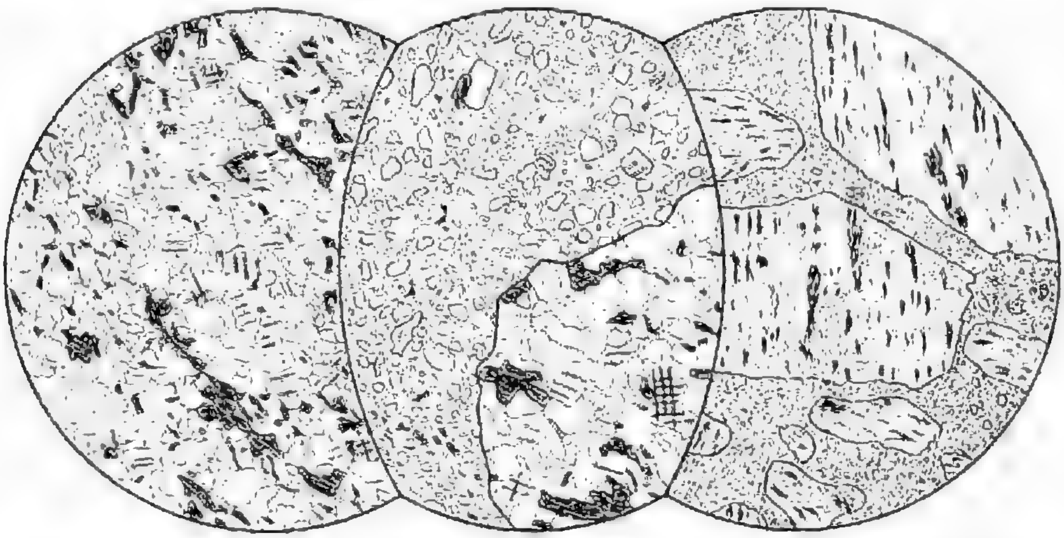


Fig. 3.—(a) Granite gneiss x 6. (b) Granite gneiss tillite x 9. (c) Granite gneiss tillite x 1. These three rocks occur in the area shown in Fig. 2.

VI. CONCLUSIONS

The following conclusions have been drawn from the present study:

1. The composition of some of the basal beds of the Torrowangee Series surrounding the Poolamacca Inlier is determined to a large extent by the composition of the underlying rocks of the Willyama Complex.
2. Land ice eroded granite and deposited granite tillite immediately above. In the same way granite gneiss tillite was deposited above granite gneiss.
3. These basal beds are of variable thickness and extent and show no stratification, but are overlain by the normal glacigene sediments (tillites, siltstones, quartzites and marbles) of the Torrowangee Series.
4. The granite plutons of the area are pre-Torrowangee in age and intrude the granite gneiss of the Willyama Complex.

ACKNOWLEDGMENTS

The writer wishes to acknowledge research grants given by the University of Adelaide and the University College of Swansea, aerial photographs from Zinc Corporation Limited, Broken Hill, facilities for chemical analysis at the Department of Geology, Imperial College of Science and Technology, London, and the generous hospitality of Mr. and Mrs. R. B. Nevins at Poolamacca Head Station.

Fig. 1.—Granite tillite (left) and bedded tillite series (right)—half mile W.N.W. of Poolamacca H.S.

Fig. 2.—Granite tillite (left) and bedded tillite series (right)—one-third mile W.N.W. of Poolamacca H.S.

Fig. 3.—Granite outcrops—western part of Western Poolamacca Pluton.

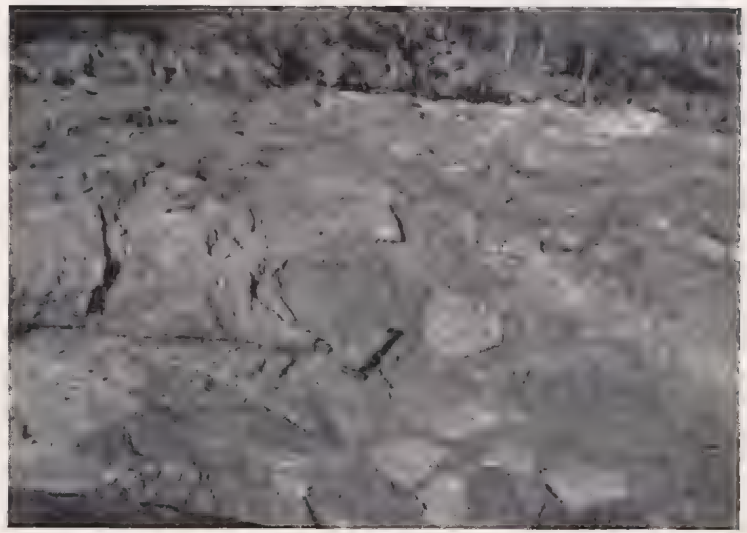


Fig. 4.—Granite tillite outcrops—near N.W. margin of Western Poolamacca Pluton.

Messrs. Haddon F. King and B. P. Thomson (Zinc Corporation Limited, Broken Hill), Professor Sir Douglas Mawson, Dr. A. W. Kleeman and Messrs. R. B. Leslie and A. J. R. White (University of Adelaide) have assisted greatly by helpful discussions in both the field and the laboratory.

BIBLIOGRAPHY

ANDREWS, E. C., 1922. The Geology of the Broken Hill District, Mem. Geol. Surv. N.S.W., 8.

JOHANNSEN, A., 1932. A Descriptive Petrography of the Igneous Rocks, Vol. II, University of Chicago Press, Chicago.

KING, HADDON F., AND THOMSON, B. P., 1953. The Geology of the Broken Hill District. Fifth Empire Mining and Metallurgical Congress Australia and New Zealand. Vol. I. Geology of Australian Ore Deposits. Aust. Inst. Min. and Met., Melbourne.

LESLIE, R. B., AND WHITE, A. J. R., 1955. The grand unconformity between the Archaean (Willyama Complex) and the Proterozoic (Torrowangee Series) north of Broken Hill, N.S.W. Trans. Roy. Soc. S. Aust., 78.

MAWSON, D., 1912. Geological investigations in the Broken Hill area. Mem. Roy. Soc. S. Aust., 2.

NOTES ON THE ACARINE GENUS *OPHIOPTES*, WITH A DESCRIPTION OF A NEW AUSTRALIAN SPECIES

BY *R. V. SOUTHCOTT*

Summary

Mites of the genus *Ophioptes* Sambon 1928 are ectoparasites of Colubrid snakes, in whose scales they form pits. Three South American and one Asian species have been described hitherto. *Ophioptes samboni* n. sp. is described, parasites upon the Colubrid snake *Rhynchoelaps fasciolatus* (Günther *1872)* from north Queensland; it is nearest to O. *coluber* Radford 1947, from India. A key to the known species is provided, and the homologies of the genus are discussed. The genus is removed from the family Myobiidae to a new family Ophioptidae.

NOTES ON THE ACARINE GENUS *OPHIOPTES*, WITH A DESCRIPTION OF A NEW AUSTRALIAN SPECIES

By R. V. Southcott

[Read 13 Oct. 1955]

SUMMARY

Mites of the genus *Ophioptes* Sambon 1928 are ectoparasites of Colubrid snakes, in whose scales they form pits. Three South American and one Asian species have been described hitherto. *Ophioptes samboni* n. sp. is described, parasitic upon the Colubrid snake *Rhynchoelaps fasciolatus* (Günther 1872) from north Queensland; it is nearest to *O. coluber* Radford 1947, from India. A key to the known species is provided, and the homologies of the genus are discussed. The genus is removed from the family Myobiidae to a new family Ophioptidae.

INTRODUCTION

In 1928 Sambon described *Ophioptes parkeri* as a new genus and species of mite, parasitic upon the banded Colubrid snake *Erythrolamprus aesculapii* (L.), from Buenavista, Bolivia. This mite caused pits in the scales of the host. Sambon described two stages in the life history of the mite, and placed it in the family Cheyletidae, where it occupied an anomalous position. Sambon commented, however, upon certain characters more suggestive of affinities with the Sarcoptiformes than with the Prostigmata of the Trombidiformes. Sambon added a further note about further specimens of the genus received at the time of going to press, and allotted some of these to a further species *O. oudemansi* Sambon 1928, which he characterized briefly, but without figures. Although he promised to describe these further mites in a subsequent paper on the "Ophidian Mites," apparently this intention was not realized by the time of his death in August, 1931.

In 1933, Ewing described a further species—*O. tropicalis* Ewing 1933, from the Colubrid snake *Erpetodryas carinatus* (L.), from British Guiana. Like Sambon's species, it also produced pits in the scales of its host.

In 1947, Radford described a further species, *O. coluber*, from the "copper-headed rat-snake (*Coluber radiatus* Schlegel)" from Imphal, Manipur State, India. As with the preceding authors, he allotted the genus to the family Cheyletidae. Thus there has been a total of four species described for *Ophioptes*, three from South America, and one from the mainland of Asia.

In the present paper a new species of the genus—*O. samboni* n. sp.—is described, an ectoparasite upon the banded Colubrid *Rhynchoelaps fasciolatus* (Gunther 1872) from north Queensland. The opportunity is taken of studying the affinities of the genus.

Ophioptes samboni n. sp.

Description of Adult (Figs. 1-3, 5, 7; Fig. 1 and the description are from specimen ACC193A; Fig. 2 is from specimen ACC193B; a third specimen, ACC193C, has also been compared): Body ellipsoidal, soft, transverse; width 425μ, length 345μ (425μ to front of capitulum). Integument soft, thin, not striated. Eyes absent. Dorsum with an anterior group of fine stiff lanceolate spiniform setae in its anterior half, setae 16-28μ long. A further group of four similar setae, smaller, 14-20μ long, is situated at the posterior pole of the dorsum. All these dorsal setae are slightly "shouldered," as occurs in e.g. the dorsal setae of *Sarcoptes scabiei*.

The venter is strengthened by the epimera of the coxae. To each of the first three coxal areas there is a single spiniform seta, 16-20μ long; a similar pair 16μ long to the sternal area. There are two pairs of stout nautilus-like bosses or pegs, with a series of curved grooves, on the epimera of the second pair of coxae, 14μ long by 10μ wide (Figs. 2, 5) (nautalae). The anterior pair is situated immediately posterior to the pair of sternal setae. These "nautalae" resemble somewhat the dorsal "notothoracic spines" of e.g. *Sarcoptes scabiei* (Fig. 6); the latter are, however, without the series of groovings, and articulate with an extensive seta base.

The genitalia cannot be seen in much detail, but in all specimens a pair of labia meet in an inverted Y, immediately in front of the anus. No sign of the dorsal penis described by Sambon in *O. parkeri* can be found. Around the anogenital area is a series of short spiniform setae, arranged as figured, 12-18μ long.

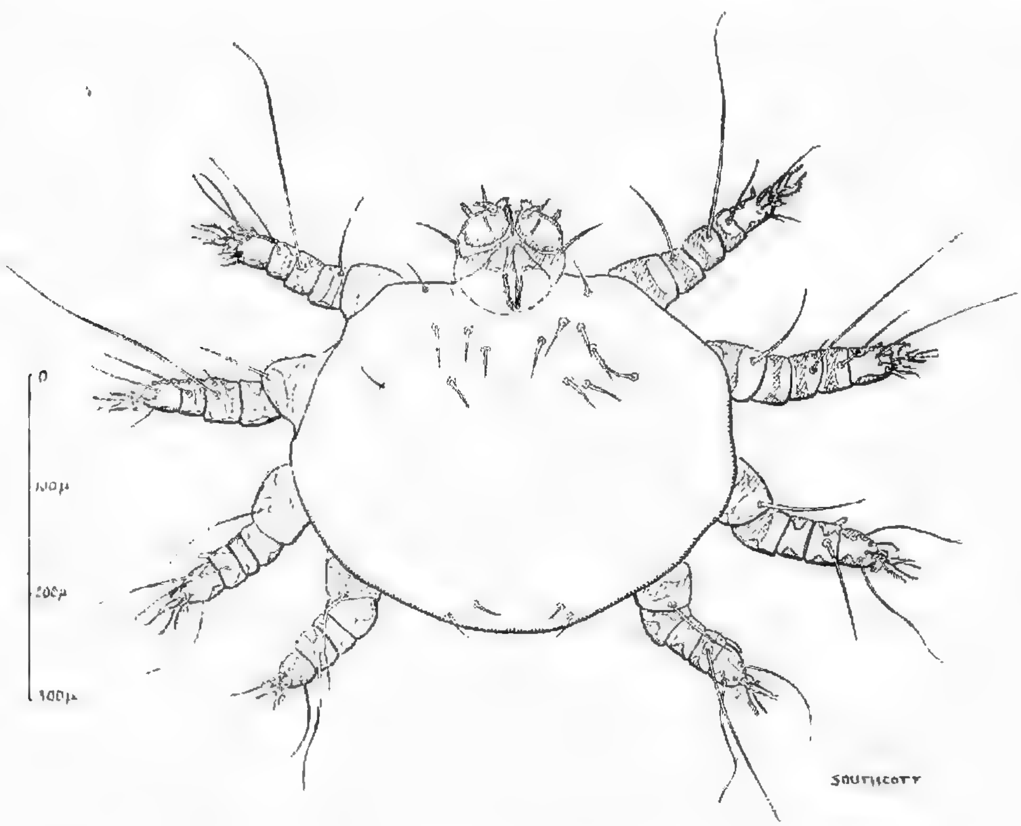
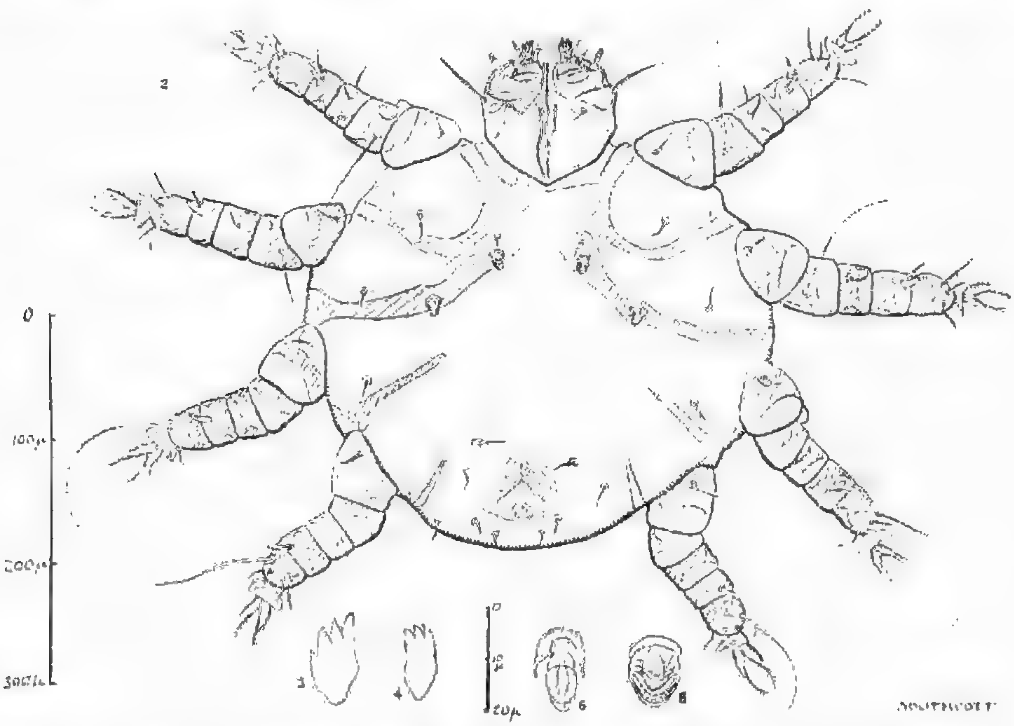


Fig. 1.—*Ophioptes samboni* n. sp., dorsal view, entire (specimen ACC 193A).

The legs are short and stout, with a weak integument, but are strengthened internally by chitinous sheets, which are much thicker than the integument. Each leg consists of six segments — coxa, trochanter, femur, genu, tibia, tarsus. The coxae are not clearly demarcated on the venter. The chaetotaxy of the legs is as follows:

Leg I: Trochanter with one short curved spiniform seta 20μ long, on its ventral aspect. The femur has two long tapering setae, the anterodorsal the stouter, pointed, faintly ciliated with adnate ciliation, 72μ long, the postero-ventral simple, whip-like, 60μ long. Genu with a long, simple, whip-like seta 190μ long, situated dorsally; ventrally a short spiniform seta 20μ long, with a

few barbs; anteriorly a spiniform seta 18μ long. Tibia dorsally with a spiniform seta with adnate ciliations, 45μ long; ventrally with a blunted peg with one or two adnate ciliations, 16μ long by 6μ wide, and alongside this peg a spiniform seta with adnate ciliations, 30μ long. Tarsus dorsally with two rows of setae, a proximal and a distal; the proximal row of two setae — a striate expanded spindle-like peg 9μ long by 4μ wide (a modified solenidion or solenoidal seta = striate seta), situated anteriorly, and a spiniform seta 65μ long, slightly bent at the tip (this seta is duplicated on the left side): the distal dorsal row overhanging the sucker or caruncle, two of them falciform ("L-shaped"), with a single faint dorsal adnate ciliation, each 18μ long; the other two are conjugate, one striate, 26μ long, and posteriorly a smaller spiniform seta, 14μ long (this latter is duplicated on the left side). Ventrally a row of four setae, all spiniform, the anterior 30μ long, then two similar, each 11μ long, then one curved, 15μ long.



Figs. 2-6.—Figs 2-3 *Ophioptes samboni* n. sp.: Fig. 2, ventral view, entire (specimen ACC 193B), to scale on left; Fig. 3, apical tarsal seta of palp. Fig. 4, apical tarsal seta of palp of *O. coluber* Radford (from a paratype). Fig. 5, coxal spine or nautala of *O. samboni* n. sp. Fig. 6, lateral dorsal seta of an adult female *Sarcoptes scabiei* (DeGeer 1778). (Figs. 3-6 to scale shown.)

Leg II: Trochanter with a similar (as in I) seta ventrally, 20μ long. Femur II as in Leg I, with anterodorsal seta 80μ long, posteroventral 80μ long. Genu as in I, with dorsal spiniform seta 235μ long, ventral spiniform seta 18μ long. Tibia: dorsal spiniform seta with lightly barbed ciliations, seta 60μ long; ventrally a thick peg 18μ long by 5μ wide, with adnate ciliations, and a spiniform seta with a few ciliations, 24μ long. Tarsus: setae as in Leg I.

Leg III: Trochanter dorsally with a long spiniform seta with faint adnate ciliations, 85μ long; ventrally a spiniform seta 21μ long. Femur and genu nude. Tibia dorsally with a long spiniform seta with adnate ciliations, 95μ long; ventrally a stout peg-like seta with adnate ciliations, tapering slightly, a little blunted, 21μ long by 5μ wide. Tarsus III dorsally with two long spiniform setae, curved, tapering and finally becoming filiform, 100μ long. There are no

solenoidal (striate) setae, but otherwise the chaetotaxy is the same as in tarsi I and II. There are two L-shaped (falciform) setae, and one short spine.

Leg IV: Chaetotaxy as in Leg III, the only difference being that the dorsal tibial seta is long, tapering, simple 165μ long.

The tarsus of each leg is provided apically with a peculiar modified empodium, but is without lateral claws. The empodium ("difurcula") is as described in other species of the genus — a fine dichotomous fork gives rise to a further similar structure at its forking. The pitchfork-like branches are delicately fringed, and taper gracefully to fine points. Each tarsus has a large cup-shaped sucker, as figured, typically Sarcoptoid in appearance. Presumably the empodium functions as a tactile organ, and aids the sucker (caruncle) below it.

The capitulum is stout, compact and broad. There has been considerable simplification of its structure, so that the interpretation of its segmentation is difficult. As in the legs, the segments of the palpi are strengthened internally by chitinous bands. An interpretation of the segmentation of the palpi is offered in Figure 7. On the ventral surface of the basis capituli is a pair of bristles, 14μ long, taken as the hypostomal setae. A strong external spine is present at the base of the palp laterally, 47μ long; this is interpreted as the femoral seta. A stout, blunt process, with adnate ciliations, 16μ long, placed anterolaterally upon the palp, is interpreted as the lateral tibial seta. A similar seta, slightly curved, 20μ long, placed dorsally toward the tip of the palp is considered as the dorsal tibial seta (or possibly the genual seta). The palpal genu and tibia are fused to a genotibia; at the apex of this there is a normal, slender bifurcate tibial claw, with the dorsal prong over-reaching the ventral. The palpal tarsus is also somewhat modified. Apically it bears a seta modified to a broad four-toothed process, roughly in the shape of a human foot, 16μ long by 10μ wide at its widest part (somewhat anteriorly) (see Fig. 3). The "toes" are stout and pointed, and point anteriorly and slightly upwards; the medialmost toe, like the hallux, extends furthest forwards. The palpal tarsus carries also two stout spiniform setae, the lateral 11μ long, the medial 20μ long.

The chelicerae are styliform, and extend back within the body of the capitulum to form an elbow, and then recurve forwards to a point in about the middle of the substance of the capitulum.

Locality: Three specimens (ACC193A, B, C) parasitic upon a banded Colubrid snake (*Rhynchoelaps fasciolatus* (Günther 1872)) (identified by E. W. Jensen), collected in the vicinity of Wondecla, North Queensland, received Sept. 1943, apparently collected a few months before, name of collector unknown (snake preserved in alcohol in the Regimental Aid Post of the 2nd/8th Australian Infantry Battalion).

The species is named in honour of L. W. Sambon, 1866-1931, who originally described the genus, and who was a noted epidemiologist.

The Systematic Position of Ophioptes samboni *n. sp.*

The following key is offered for the separation of the five species now allotted to the genus (based on the keys of Sambon, Ewing and Radford, the examination of *O. samboni* and a paratype of *O. coluber*).

A Each tarsal sucker consisting of two divergent hollow pads .... *O. oudemansi* Sambon 1928

AA Each tarsus with a cup-shaped sucker (caruncle).

B On the dorsum, above legs 2, 3, and 4, situated peripherally, there is a long spiniform seta. Lateral tibial palpal seta clavate .... *O. parkeri* Sambon 1928

BB No long setae laterally on the dorsum. Lateral tibial palpal seta tapering.

C The anteromedian group of dorsal setae large and conspicuous; dorsal body setae near capitulum as long as the palpi........ *O. tropicalis* Ewing 1933

CC Anteromedian group of dorsal setae shorter.

D A posterior dorsal group of 4 setae present. Solenoidal setae on tarsus I and II form spindle-shaped pegs. The foot-like seta at the apex of the palpal tarsus with 4 "toes" (Fig. 3)..............................*O. samboni* n. sp.

DD Posterior dorsal group of 8 setae present (i.e. anus at posterior pole of body). Solenoidal setae on tarsus I and II form conical pegs. The foot-like seta on the palpal tarsus with three distinct "toes" (Fig. 4)....*O. coluber* Radford

7

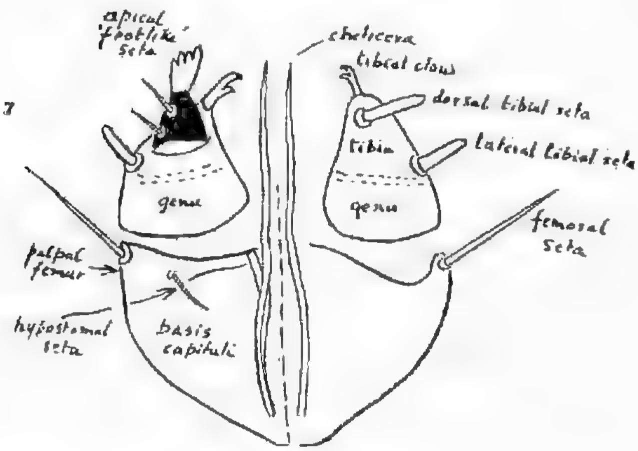


Fig. 7.—Suggested interpretation of the structure of the mouthparts in *Ophioptes.*

Ophioptes samboni n. sp. is considered closest to its nearest known neighbour geographically, *O. coluber* Radford, from Imphal, Manipur State, India. It is, however, not possible to make more complete comparisons with the other species. Furthermore, as none of the developmental stages of *O. samboni* were available, only the adult stages have been considered in this paper. In the adult of *O. parkeri*, apart from a reference to the anus, which is depicted in stipple, along with the anal setae, no figure or description of the ventral surface was offered by Sambon. Sambon mentioned the presence of cone-shaped spines (nautalae) upon the venter of *O. oudemansi*, and it is inferred that these are not present in *O. parkeri*. This latter would be surprising, as they have now been observed in each of the other species of the genus. It may also be well to mention here that what are called the coxa, trochanter, femur and tibia in the legs by Radford should properly be called trochanter, femur, genu and tibia. Although the actual term employed is arguable in the cases of the genu and tibia, this is not the case with the more proximal leg segments. The coxa is not a movable segment; Radford has missed the weakly defined coxae on the body, and called the first movable segment (trochanter) the coxa. Radford also states that the dorsum of *O. parkeri* bears long spines above legs i-iii; reference to Sambon's figure shows that this should read ii-iv.

Sambon described a dorsal genital orifice with a penis in his type adult specimen of *O. parkeri*, and took his specimen (?specimens) as male. This structure has not been observed subsequently in the genus by either Ewing, Radford or myself, and if the validity of Sambon's observations be accepted, all the specimens that have been described since have been females. It is not at present possible, therefore, to elucidate intraspecific sexual morphological

differences. However, Radford claims that the female sexual orifice is present in the anterior part of the dorsum in *O. coluber*, in the position in fact described by Sambon for the male sexual orifice. I have examined carefully a paratype specimen of *O. coluber*, in the collection of the South Australian Museum, and have been unable to find any trace of an aperture in the position described by Radford, nor is there one in any of the three specimens of *O. samboni*. The genitalia externally in this paratype of *O. coluber* are in fact as described above in *O. samboni*, but the anus is at the posterior pole of the body. Ewing (1933), in his account of the maturer instars of *O. tropicalis*, stated "Anus a longitudinal slit, in front of which is a bilobed fold, and in front of this fold a transverse sclerotized lip," and figures the perineum accordingly; this, with minor modification, agrees with the description and figure submitted here for *O. samboni*. It is conceivable that Radford had a male specimen before him, and not a female as he had postulated: however, the clarification of this problem must be left to the future.

THE AFFINITIES OF THE GENUS OPHIOPTES

Sambon (1928) remarked that "At first sight, this scale-inhabiting acarian suggested some new kind of Sarcoptoid mite to be placed between the Sarcoptidae . . . and the Analgesidae . . . but, notwithstanding the presence of conspicuous cup-shaped suckers on (the) tarsi, the microscope at once revealed unmistakable Cheyletid characters." The structure of the body and legs show considerable resemblance to that of the Sarcoptiformes. There is, as Sambon remarked, a large sucker or caruncle to each tarsus; and, as occurs in many of the Sarcoptiformes, there are no lateral claws to the empodium. The coxae are weak, and are represented by epimera. There are, however, no genital or adanal suckers. The mouthparts, although highly modified, are in the character of the Trombidiformes. The chelicerae are styliform, and the palpi are modified for clinging. Baker and Wharton (1952), in their textbook of acarology, removed the genus to the family Myobiidae, but commented that it occupied a somewhat intermediate position between the two families. In the Myobiidae, however, the forelegs typically are modified to an appendage for grasping the hairs of the mammalian host; also the tarsus of the legs carries one or two conspicuous claws, and there is no sucker (caruncle). The reduction of the palpi, the lack of tarsal claws to the legs, and the reduction of the coxae, likewise separate *Ophioptes* from the Cheyletidae.

It is apparent that by the standards adopted for classification within the Trombidiformes, that the genus *Ophioptes* is deserving of family status at least, and is therefore allotted to the family Ophioptidae n. fam., within the Prostigmata of the Trombidiformes.

Ophioptidae n. fam.

Definition: External parasites of Colubrid snakes, producing typically pits in the scales of the host. Chelicerae styliform. Palpi reduced, with a fused genotibia. Coxae of legs reduced to epimera. Developmental stages unknown, apart from a pre-adult pupal stage. With a single genus, *Ophioptes* Sambon 1928, at present known.

REFERENCES

Baker, E. W., and Wharton, G. W., 1952. An Introduction to Acarology. The Macmillan Company, New York. Pp. 1-465 and xiii.

Ewing, H. E., 1933. A New Pit-producing Mite from the Scales of a South American Snake, J. Parasitol, 20 (1): 53-56.

Radford, C. D., 1947. Parasitic Mites from Snakes and Rodents (Acarina: Cheyletidae, Listrophoridae and Laelaptidae), Proc. Zool. Soc. 117 (1): 228-240.

Sambon, L. W., 1928. *Ophioptes parkeri.* A New Species and Genus of Cheyletid Inhabiting the Scales of Reptiles. Ann. Trop. Med. & Parasitol. 22 (1): 137-142.

NOTES ON THE YOUNGER GLACIAL REMNANTS OF NORTHERN SOUTH AUSTRALIA

BY L. W. PARKIN

Summary

The distribution of undoubted glacial erratics lying upon the Cretaceous marine sediments of the central part of South Australia has intrigued many geologists since they were first noted by H. Y. L. Brown in 1894. The erratics which consist of a variety of sedimentary and igneous rocks have been observed particularly in the area from Marree west and south-west to the vicinity of Stuarts Range opal fields and south to McDouall Peak-in fact, along the south-westerly margin of the Cretaceous marine deposits.

Many have made the natural assumption that these boulders have been distributed by floating ice in late Cretaceous times though others object that there is no evidence of conditions suitable for glaciation at that time, that on the contrary the period was one of general warmth, with tropical conditions prevailing.

Recent observations made while carrying out detailed geological surveys in the Peake and Denison Ranges have led the present writer to review the literature on this interesting problem and to present additional evidence suggesting the probable means by which the erratics acquired their present distribution.

NOTES ON THE YOUNGER GLACIAL REMNANTS OF NORTHERN SOUTH AUSTRALIA*

By L. W. Parkin†

[Read 10 Nov. 1955]

INTRODUCTION

The distribution of undoubted glacial erratics lying upon the Cretaceous marine sediments of the central part of South Australia has intrigued many geologists since they were first noted by H. Y. L. Brown in 1894. The erratics which consist of a variety of sedimentary and igneous rocks have been observed particularly in the area from Marree west and south-west to the vicinity of Stuarts Range opal fields and south to McDonall Peak—in fact, along the south-westerly margin of the Cretaceous marine deposits.

Many have made the natural assumption that these boulders have been distributed by floating ice in late Cretaceous times though others object that there is no evidence of conditions suitable for glaciation at that time, that on the contrary the period was one of general warmth, with tropical conditions prevailing.

Recent observations made while carrying out detailed geological surveys in the Peake and Denison Ranges have led the present writer to review the literature on this interesting problem and to present additional evidence suggesting the probable means by which the erratics acquired their present distribution.

PREVIOUS INVESTIGATIONS

H. Y. L. Brown (1894) makes first reference to the occurrence of glaciated boulders observed during a geological expedition in the area between Mt. Paisley and Strangways Springs. He noted waterworn boulders of considerable size composed of quartzite, sandstone and quartz felspar porphyry, the latter being particularly common, and suggested that as the nearest source of this rock is the Gawler Ranges, the material came to its present position by drift ice from the south.

Brown returns to the subject later (1898) where he records the occurrence of erratics near Mt. Eba, and again (1902) when he notes them near William Creek and Anna Creek. Again during a trip west from Stuarts Creek Station (1905) erratics are recorded in plenty. In this latter publication he draws attention to a stray granite pebble encountered in the Lake Phillipson bore at a depth of 3,100 feet embedded in shales of pre-Jurassic age and suggests therefore that the action of ice is indicated in this earlier period.

Edgworth David (1906) reviews the evidence presented by Brown and suggests the possibility that the erratics could be derived by reworking of older glacigenes such as those already recognised at Crown Point in Central Australia. The subject was by this time quite controversial, with Howchin (quoted by David *op. cit.*) also favouring a re-distribution of older glacial material, probably of Sturtian age which was known to outcrop near Marree. David later changed his views and contended strongly (1923) that the glacia-

* Published by permission of the Director of Mines.

† Geological Survey of South Australia.

tion was probably upper Cretaceous — his co-author (Howchin) perhaps dissenting.

R. L. Jack (1915) records the occurrence of Sturtian tillite near Mt. Chandler west of the Alberga River — the most northerly occurrence of this formation then known — and again draws attention to the presence of superficial erratics in the area west of the Peake and Denison Ranges near Lake Conway, six miles west of Warrina. Jack is here of the opinion that only Cretaceous drift ice can explain the phenomenon, a point of view which he maintains (1931) following geological traverses to the north and north-west of Tarcoola. In this publication he records blue marine Cretaceous shales containing erratics, with diminution in size and frequency from south to north corresponding with a drift ice movement in that direction. He records that erratics are frequently found on top of and adjacent to the low outcrops of basement gneiss, and in particular refers to Mt. Woods, elevation about 100 feet of gneissic rock, with erratics distributed about its base but not on the upper slopes. He figures a map showing the distribution of erratics which are particularly common in the McDonall Peak-Coober Pedy area. L. Keith Ward (1925) also features a map showing that the erratics lie between the limits of upper and lower Cretaceous sediments as mapped in the area west of Marree and north of the Transcontinental railway. From observations made near Dalhousie Mound Springs to the north of Oodnadatta, he places glaciation as late as Upper Cretaceous. He reviews evidence from other parts of the world for a precedent and finally contends that glaciation of this age is a permissible deduction.

Woolnough and David (1926) contributed a new piece of evidence following a visit to Moolawatana near the north-east extremity of the Flinders Ranges, where they observed erratics associated with Cretaceous marine fossils in a dissected creek bank adjacent to the ranges. While admitting that the association is not here conclusive, in that the fossiliferous material occurs as fragmental boulders not *in situ*, the authors nevertheless contend that the circumstantial evidence is particularly strong. This observation when allied to his previous views led David to consider the case for Cretaceous glaciation as established and it so appears in his final memoir (1950), "The Geology of the Commonwealth of Australia."

Howchin (1928) critically reviews all the evidence and contests the view that glacial conditions could have existed in Cretaceous times. He points out that a large part of the continent was below sea level, the sea itself being an extensive gulf of the tropical ocean. He is unable to agree that any highlands of sufficient altitude could have existed to provide snowfields or that if they did exist, drift ice could have survived to distribute boulders so widely. He suggests that it is more likely that reworking of Sturtian or Permian tills has provided the material now under question.

Howchin in this same publication deals with the Moolawatana evidence and is happy to dismiss it as an outwash from the nearby Sturtian tillite, a view which accords with the most recent observations (G. D. Woodard, 1955).

While reviewing the opinion of previous observers on this problem, it is pertinent to include reference to the evidence of younger glaciation established *in situ* beyond controversy. Mention has already been made of the Crown Point occurrence described finally by David and Howchin (1923) and which has been correlated to the satisfaction of all with the widespread glaciation of the Australian continent in the late Palaeozoic (Permian). The Lake Phillipson bore has also provided evidence which, there is no reason to doubt, indicates glacial action of the same period, and similarly a diamond drill hole near Anna Creek railway siding produced evidence of pre-Jurassic glaciation in the form of a perfectly soled pebble at a depth of 800 feet.

RECENT FIELD EVIDENCE

During regional geological mapping in the area between William Creek and Oodnadatta by the Geological Survey of South Australia, glaciation was recorded in several areas which are described by Reyner (1955) and illustrated by the published Geological Survey Standard 1-mile Atlas sheets Algebuckina, Nilpinna, Conway, Umbum, Boorthanna, Cadlareena, and Anna.

Sturtian tillite is well represented on the Boorthanna and Cadlareena sheets, but does not appear in outcrop north of latitude 28° 40'. This occurrence of Sturtian tillite has not previously been recorded.

Four miles north of Warrina Siding (Map Sheet Nilpinna), a small pocket of typical unconsolidated till is exposed in a creek on the western foothills of the pre-Cambrian Peake and Denison Ranges where it lies directly upon pre-Cambrian bedrock. A feature of this till is the predominance of erratics of Sturtian tillite, many of which are facetted and striated. This is clearly a continental morainic deposit which has been preserved *in situ* and its similarity to portions of the recognised Permian occurrences in the southern part of the State is striking.

A similar though perhaps less convincing occurrence appears six miles south of Edwards Creek siding, shown on Map Sheet Conway. In the south-east corner of the Boorthanna sheet are widespread glacial erratic fields lying on high level pre-Cambrian bedrock which are evidently remnants of a similar till.

Howchin (1928) in a footnote refers to a glaciated pebble brought in from near Mt. Dutton. The source of this specimen has been located in the field (Map Sheet Algebuckina) on the western slopes of the pre-Cambrian inlier of the Mt. Dutton Range. Here there is an erratic field lying at an elevation above that of the Cretaceous marine formation which to the west laps on to the inlier. Amongst the erratics scattered along the slope of the range there is again a large proportion of boulders of Sturtian tillite many of which are markedly striated.

CONCLUSIONS

The occurrence of facetted erratics of Sturtian tillite in the younger till and amongst the remnant erratic fields some 60 miles from the nearest outcrop of this material (in the case of Mt. Dutton), of course, precludes the possibility as suggested *inter alia* by Howchin that the erratics may be derived directly by erosional reworking of the Sturtian. Further, it is very apparent that even now these erratics are in process of being separated from their unconsolidated matrix and dispersed by periodic outwash floods upon the younger sediments.

There is admittedly no evidence available to provide a direct correlation of these till occurrences with the Permian of Crown Point to the north and Hallett Cove to the south, but since glaciation at that time must be presumed to have been general between these widely spaced points there is no necessity to invoke another glacial epoch to account for their presence.

It is suggested therefore that continental glacial debris was scattered upon the pre-Cambrian basement during the Permian, many of the accumulations being in high level pockets. With the encroachment of the Cretaceous sea the material has been re-worked and much incorporated into the marine deposits, although some of the higher level material remained beyond reach.

The pre-Cretaceous physiography was apparently one of very marked relief with mountain ranges in the Marree, Coward Springs and Mt. Dutton area and many isolated peaks to the south and west. For example, the bore at Lake Phillipson penetrated over 3,000 feet of sediments, whereas basement rock outcrops only 12 miles distant. Under such conditions it can readily be pictured that Permian glacial till would be continually incorporated into the marine formations deposited during the Cretaceous.

This view, it is felt, adequately explains all the observed phenomena. Particularly does it explain the location of the erratics around the southern and south-western margins of the Cretaceous area and adjacent to bedrock highs.

A similar condition is applying even at this time along the shore of the St. Vincent Gulf where coastal pockets of Permian till are being broken up, and the erratics from these are lodging in present day marine littoral deposits.

REFERENCES

BROWN, H. Y. L., 1894. "Report on the Geology of the Country from Strangways Springs to Wilgena," Annual Report, Govt. Geologist, South Aust. Parl. Paper No. 25.

BROWN, H. Y. L., 1905. "Report on Geological Explorations in the West and North West of South Australia," Sth. Aust. Govt. Parl. Paper No. 71.

DAVID, T. W. EDGWORTH, 1906. International Geol. Congress, Pt. 1, pp. 463-465.

DAVID, T. W. EDGWORTH, and HOWCHIN, W., 1923. Report of Glacial Research Committee, Aust. Assoc. Adv. Sc., Vol. XVI, pp. 74-94.

DAVID, T. W. EDGWORTH, 1950. Ed. W. R. Browne. "The Geology of the Commonwealth of Australia," London.

HOWCHIN, W., 1928. "The Building of Australia and the Succession of Life," Pt. II, pp. 287-291, British Science Guild.

JACK, R. L., 1915. "Report on the Region to the North and North-west of Tarcoola," Geol. Survey, Sth. Aust. Bull. 5.

JACK, R. L., 1931. "The Geology of the Western Portion of the Great Artesian Basin," Geol. Surv. Sth. Aust. Bull. 15.

REYNER, M. L., 1955. "The Geology of the Peake and Denison Ranges, Sth. Aust." Geol. Surv. Sth. Aust. Report of Investigations, Series No. 6.

WARD, L. KEITH, 1925. "Notes on the Geological Structure of Central Australia," Trans. Roy. Soc. S. Aust., Vol. 49, pp. 61-84.

WARD, L. KEITH, 1928. "A New Edition of the Geological Map of South Australia," Annual Rept. Govt. Geol. Sth. Aust., pp. 9-22, Parl. Paper No. 26.

WOODARD, G. D., 1955. "The Stratigraphic Succession in the Vicinity of Mt. Babbage Station, South Australia," Trans. Roy. Soc. S. Aust., Vol. 78.

WOOLNOUGH, W. G., and DAVID, T. W. EDGWORTH, 1926. "Cretaceous Glaciation in Central Australia," Quart. Journal Geol. Soc. Lond., Vol. 82, pp. 332-351.

CHLORINITIES OF COASTAL WATERS IN SOUTH AUSTRALIA

BY L. M. THOMAS AND S. J. EDMONDS

Summary

A survey has been made of fluctuations in coastal chlorinities at ten widely scattered stations in South Australia. Samples were tested at approximately fortnightly intervals from December 1949 to April 1951.

The maximum and minimum chlorinities recorded at the ten stations were as follows:

Port Augusta 26·85$^{0}/_{00}$ and 24·55$^{0}/_{00}$; Port Wakefield 26·10 and 21·95; Streaky Bay 21·95 and 20·35; Moonta Bay 21·80 and 20·55; Port Lincoln 20·85 and 19·95; Brighton 20·85 and 20·35; Kingscote 20·75 and 19·75; Port Elliston 20·20 and 19·50; Victor Harbour 20·20 and 16·05; Robe 20·15 and 19·00. General and local reasons for these fluctuations are discussed.

Chlorinities in these waters, especially in Spencer and St. Vincent Gulfs, are strongly influenced by high local evaporation, low rainfall and small surface run-off, resulting in extremely high chlorinities at the heads of the two Gulfs.

It is possible that this highly saline water flows southwards along the beds of the gulfs and that it mixes with the more oceanic waters at the surface near their entrances.

CHLORINITIES OF COASTAL WATERS IN SOUTH AUSTRALIA

By I. M. Thomas and S. J. Edmonds*

[Read 10 Nov. 1955]

SUMMARY

A survey has been made of fluctuations in coastal chlorinities at ten widely scattered stations in South Australia. Samples were tested at approximately fortnightly intervals from December 1949 to April 1951.

The maximum and minimum chlorinities recorded at the ten stations were as follows: Port Augusta 26·85‰ and 24·55‰; Port Wakefield 26·10 and 21·95; Streaky Bay 21·95 and 20·35; Moonta Bay 21·80 and 20·55; Port Lincoln 20·85 and 19·95; Brighton 20·85 and 20·35; Kingscote 20·75 and 19·75; Port Elliston 20·20 and 19·50; Victor Harbour 20·20 and 16·05; Robe 20·15 and 19·00. General and local reasons for these fluctuations are discussed.

Chlorinities in these waters, especially in Spencer and St. Vincent Gulfs, are strongly influenced by high local evaporation, low rainfall and small surface run-off, resulting in extremely high chlorinities at the heads of the two Gulfs.

It is possible that this highly saline water flows southwards along the beds of the gulfs and that it mixes with the more oceanic waters at the surface near their entrances.

INTRODUCTION

The coastline of the State of South Australia (see Fig. 1) is deeply dissected by Spencer Gulf and St. Vincent Gulf, remnants of an extensive marine inundation of the region which occurred in early Tertiary times. The sea receded later and at about this time block faulting raised the present Mount Lofty Ranges between St. Vincent Gulf and the lower part of the Murray Valley. These ranges are geologically continuous with Kangaroo Island which now partially blocks the entrance to St. Vincent Gulf.

The two gulfs are broad at their entrances and shallow. At its entrance, Spencer Gulf has its maximum depth of thirty to thirty-six fathoms and shoals away fairly gradually as it narrows towards its head, about two hundred and twenty miles inland. At Port Augusta it is only about half a mile wide, but it extends several miles further to terminate in mangrove swamps and mud flats. St. Vincent Gulf has a maximum depth of about nineteen fathoms at its entrance and this too shoals gradually to its head, a few miles north of Port Wakefield, about one hundred miles inland. This gulf terminates in a broad, sandy bay. Neither gulf has a significant fresh water inflow, the only considerable volume of fresh water pouring into the Southern Ocean on the South Australian coastline being from the River Murray which enters through Lake Alexandrina about fifteen miles almost due east of Victor Harbour.

Ten stations were chosen for approximately fortnightly samplings of sea water. These were at Streaky Bay, Port Elliston, Port Lincoln, Port Augusta, Moonta Bay, Port Wakefield, Brighton, Kingscote, Victor Harbour and Robe (see Fig. 1).

Chlorinity titrations, using a silver nitrate standardised against Woods Hole standard sea water, from a 50 ml. "blue line" burette were carried out as soon as practicable after the receipt of the samples at the laboratory. One 10 ml. sample from each bottle was usually tested. Only on rare occasions was there a significant divergence between the two titration figures. In such cases, titra-

* Department of Zoology, University of Adelaide.

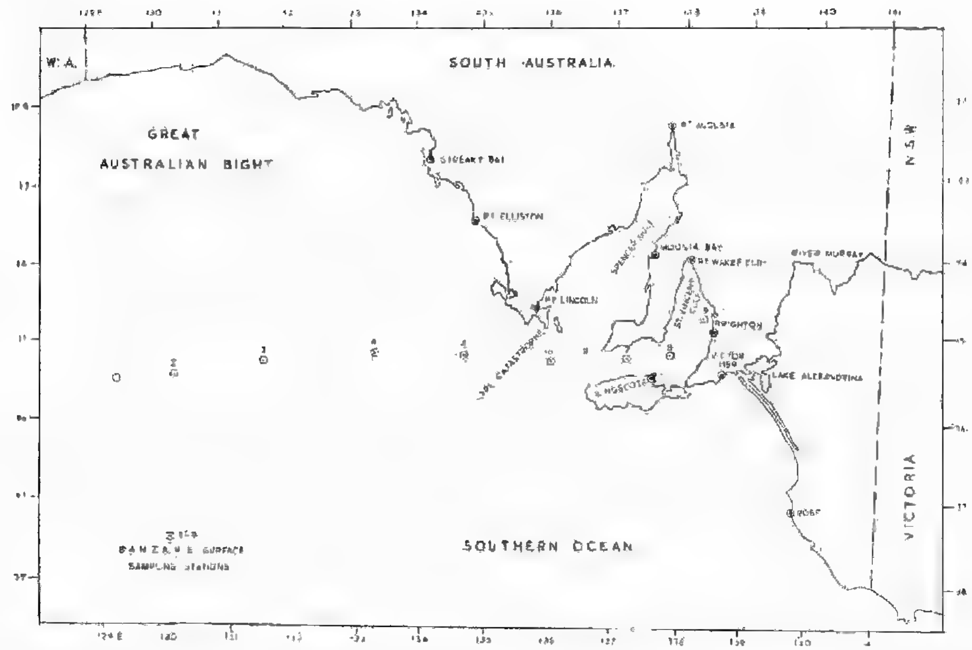


Fig. 1.—Coast of South Australia showing the positions of the ten sampling stations and the positions of nine surface stations worked by the B.A.N.Z.A.R Expedition, 1929-31, referred to in Table 3.

tions were repeated and the results averaged. Burette readings were made to the nearest 0·05 ml.

Figures 2 to 11 show the fluctuations in chlorinity during the period of the survey, namely, from December 1949 to April 1951. Weekly rainfall figures have been added and, where available, weekly averaged air temperature figures. In Figure 11 (Victor Harbour) some wind data and weekly estimated outflow from the River Murray are included.

The chlorinity figures given in this paper have been published previously without discussion as to their significance. (Thomas and Edmonds, 1953.)

Streaky Bay (Fig. 2)

The jetty where samples were taken is in a relatively small bay which offshoots from the larger water-mass of Streaky Bay itself. It is thus well protected and receives practically no direct surge from the outer ocean. The inner

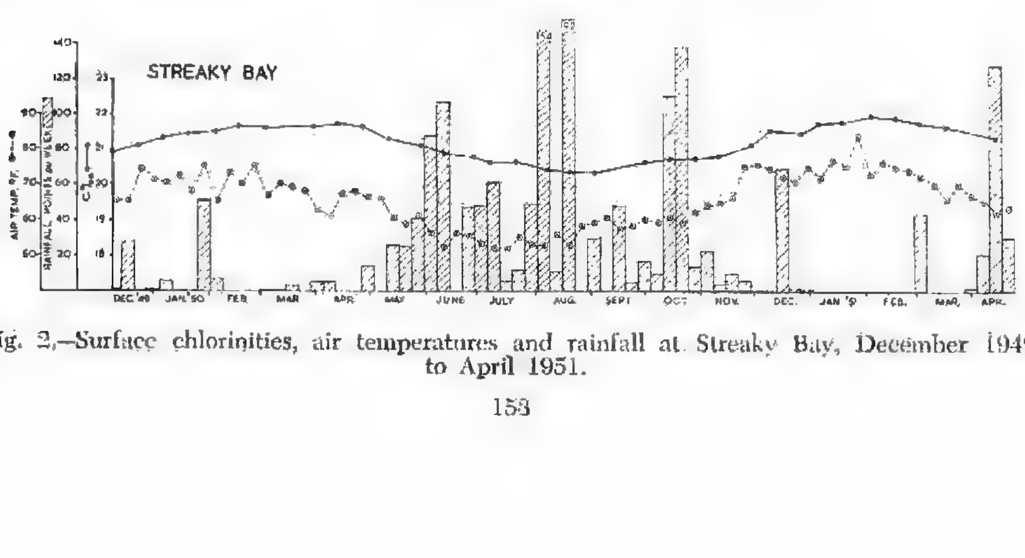


Fig. 2.—Surface chlorinities, air temperatures and rainfall at Streaky Bay, December 1949 to April 1951.

bay has a depth varying from about one and a half fathoms at the jetty to about four fathoms at its junction with the outer bay. This entrance is relatively narrow as at half tide an extensive sand bank is uncovered which blocks the entrance with the exception of a channel a few hundred yards wide. The outer bay too is moderately shallow, having a depth, over much of its area, of four to six fathoms falling to eight fathoms at its broad entrance to the Great Australian Bight.

There is no significant fresh water inflow into the southern part of the bay. At the northern end there is a small tidal creek which drains some marshy land, but which contains fresh water only after considerable rain. This is, however, too far away from the jetty to have any influence on chlorinities there.

The range of chlorinities at this station lay between 20·35‰ (September 3, 1950) and 21·95‰ (February 4, 1951). The graphed figures show a well-marked annual cycle of high chlorinities in summer and low in winter, the chlorinity curve following fairly closely that of air temperatures. There is no clear relationship between chlorinity and precipitation. Sverdrup *et al.* (1942 Chart VI) and Howard (1940) (see Fig. 1 and Table 3) give a figure of about 35·5‰ for the salinity of Bight waters, corresponding to a chlorinity of 19·66. Thus it can be seen that figures at the jetty at Streaky Bay are consistently higher than this. Evaporation must then play an important part throughout the year in the maintenance of high chlorinities here, though of course the effect is much more marked in summer. Evaporation at this station has been estimated by Trumble (1948) as 63·9 inches per annum while the mean annual rainfall is about 15 inches.

Port Elliston (Fig. 3)

As it seemed evident that Streaky Bay would not indicate clearly the chlorinity conditions in open Bight coastal waters throughout the year, Port Elliston was added to the list of sampling stations in March, 1950. This port is situated in Waterloo Bay, which is much smaller than Streaky Bay and much less protected from open water influences. The coastline of the bay forms

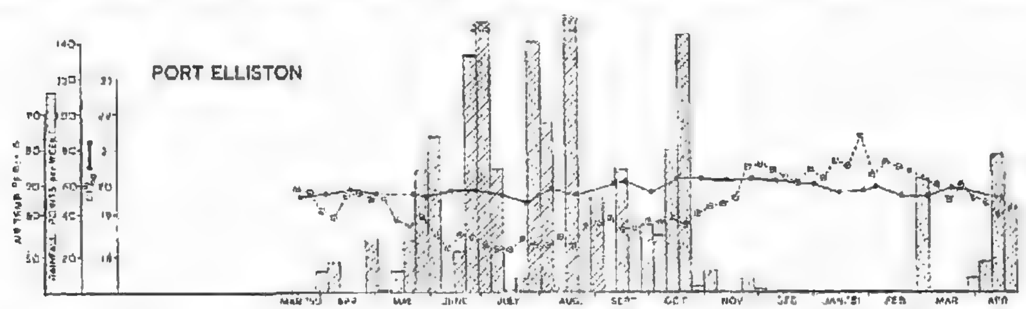


Fig. 3.—Surface chlorinities and rainfall at Port Elliston, March 1950 to April 1951, with air temperatures for Streaky Bay for the same period.

nearly three parts of a circle; the jetty, from which the samples were taken, facing the open ocean. A rocky bar, exposed at low tide, partly blocks the entrance, but there is a six-fathom channel to drain the bay which is for the most part only about three and a half to four fathoms deep. Consequently there is good circulation of sea water with each tide and this is reflected in the relatively stable chlorinity of its waters. The highest figure obtained was 20·20 (Oct. 31, 1950) and the lowest 19·50 (July 25, 1950).

There is little indication of an annual cycle as there is at Streaky Bay, the effects of evaporation being to a greater extent offset by more thorough oceanic

circulation. Annual evaporation is estimated by Trumble (1948) at 56·0 inches while the mean annual rainfall is 16·67 inches. No local air temperature records are available for this station so the figures for Streaky Bay, the nearest point on the coast for which they are available, have been plotted. They are, however, probably slightly high for Port Elliston. The chlorinity figures for this station are, on the whole, only slightly higher than those for the Great Australian Bight (Sverdrup *et al.* (1942 Chart VI)) and Howard (1940), in fact, chlorinities at this station are the nearest to oceanic conditions of any encountered in this survey. It is still evident though that evaporation is the important factor in the maintaining of the chlorinities recorded.

Port Lincoln (Fig. 4)

The jetty where the samples were taken, though in a well-protected bay, being sheltered by Kirton Point to the west and Boston Island to the north-west, has deep water, mostly eight to nine fathoms and has good tidal circulation. The maximum chlorinity recorded here was 20·85 (March 4, 1951), and the minimum 19·95 (July 18 and August 7, 1950). There is little evidence of the direct effect of rainfall but a fairly clear annual cycle is shown, the curve following in general the seasonal curve for air temperature.

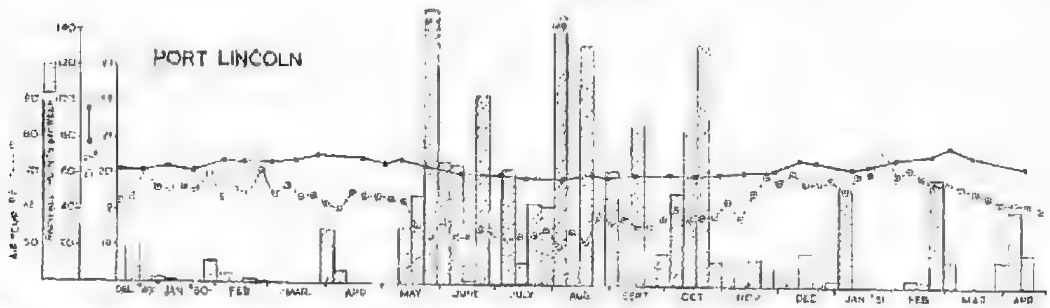


Fig. 4.—Surface chlorinities, air temperatures and rainfall at Port Lincoln, December 1949 to April 1951.

Chlorinities at this station are intermediate between those of upper gulf waters, as shown by Moonta Bay and Port Augusta, and oceanic waters. The latter seem to exert the more important influence owing to the strong currents of oceanic water which sweep up between Cape Catastrophe and Thistle Island. The effect of the highly saline upper gulf waters is shown by the generally higher chlorinity figures for this station compared with the more oceanic stations at Port Elliston, Victor Harbour and Robe. The annual cycle of high figures in summer and lower ones in winter indicate, too, that local evaporation is a factor of some importance. Trumble (1948) estimates average annual evaporation at 48·5 inches and the mean annual rainfall is 19·29 inches.

Port Augusta (Fig. 5)

This station stands nearly at the head of Spencer Gulf where it has narrowed to a width of about half a mile. This fact associated with the lower latitude of this station and its nearness to the arid interior of the continent offer a ready explanation for the extremely high chlorinities recorded. The highest readings were 26·86 (January 21 and April 4, 1951) and the lowest 24·55 (August 21, 1950). This lowest reading is far in excess of all figures from other stations with the exception of Port Wakefield. The geography of the region and conditions of tidal flow also assist in the maintenance of high chlorinities. About thirty miles south of the station, the gulf narrows abruptly at Point

Lowly to a width of about eight or nine miles. At this point, too, on the eastern coastline a long sand bar which is exposed at low water springs, juts out from Ward Point making the effective tidal channel about four miles wide. Through this there is a considerable tide race around Point Lowly. North of this point, the gulf broadens again and then narrows fairly gradually. It extends several miles beyond Port Augusta to terminate in mud flats and mangrove swamps. Admiralty charts show a tidal current of about one and a half knots

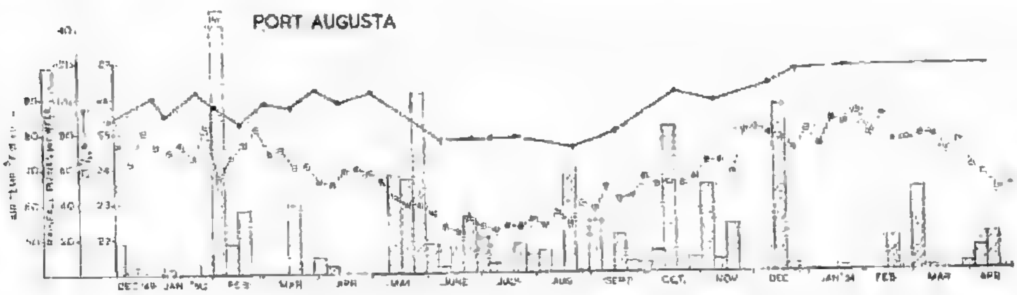


Fig. 5.—Surface chlorinities, air temperatures and rainfall at Port Augusta, December 1949 to April 1951.

between Point Lowly and Port Augusta and an average depth in mid stream of four to six fathoms. When the tide runs out, water near Port Augusta would only be able to traverse about ten of the thirty miles distance to Point Lowly before the turn of the tide tended to drive it back again. Ventilation in this part of the gulf is then very poor even though the spring tide range is twelve feet. The annual evaporation is estimated by Trumble (1948) at about 88 inches. High evaporation in the shallows north of the station, too, would contribute to these high chlorinities as would also the mean low annual rainfall of about 9·5 inches. The marked annual cycle in chlorinities is no doubt the joint effect of low rainfall, negligible run-off and high evaporation, as nearly half of the annual evaporation occurs in the three summer months, while a third of the annual rainfall occurs in the three winter months.

Moonta Bay (Fig. 6)

The range and level of chlorinities at this station fall, as might be expected, between those of Port Lincoln and Port Augusta though considerably closer to the former. The highest recording was 21·80 (July 8, 1950) and the lowest 20·55 (Feb. 2, 1950), though this latter figure was undoubtedly influenced by light rain on the day of collection. The jetty is situated in a wide, shallow bay with about one and a half fathoms at the jetty itself and four and a half to five fathoms in the bay generally. The mean annual rainfall is 14·94 inches per annum and the estimated annual evaporation 77·7 inches (Trumble 1948). The range of chlorinities is rather less than might have been expected at a station so far up the gulf. It seems to be diminished by some factor which creates high chlorinities in the winter months when they would normally be expected to be lower.

A tentative explanation of this condition is here given. Admiralty charts indicate a tidal eddy through Moonta Bay. A 1⅞ to 2¾ knot tidal current is indicated at the northern end of the bay and a ⅝ to 1½ knot current at its southern end. A 1 knot tidal current is shown some distance offshore. It is suggested that the more saline waters at the head of the gulf cool and sink in late autumn and winter and flow down its bed. The tidal turbulence at about the level of Moonta Bay causes vigorous mixing of this stream with the less

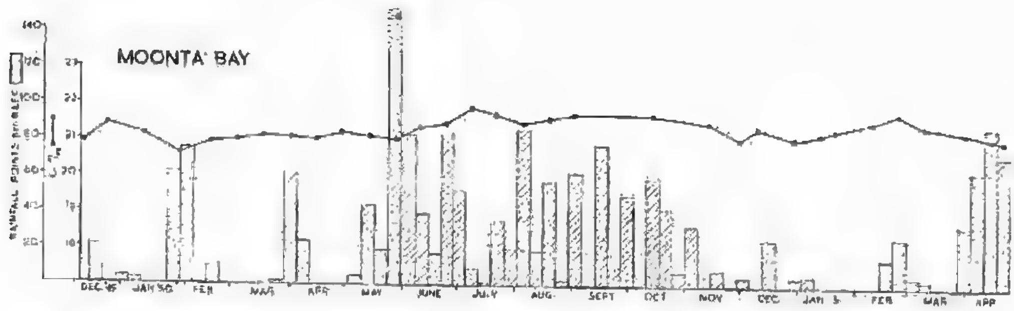


Fig. 6.—Surface chlorinities and rainfall at Moonta Bay, December 1949 to April 1951.

saline surface waters so increasing the surface chlorinity. The shallowness of the gulf will not allow of strong stratification and the prevailing sou'westerly winds would cause a piling up of water on the eastern coastline which would assist the general mixing. Thus the figures for this station rise during May, June and July and are maintained more or less at this level during the remainder of the winter. In spring and early summer, the warming and lightening of the waters at the head of the Gulf tend to check this deep southwards flow so the chlorinities at Moonta Bay show a slight decline. This is, however, soon counteracted by increased local evaporation during the summer months and the figures rise again to fall once more in early autumn with reduced local evaporation.

TABLE 1.

Hydrographical data from a station in Spencer Gulf worked by the F.R.V. "Warreen"

Date	Lat.	Long.	Sounding (fath.)	Depth (m.)	Temp. (°C.)	Cl‰	δ_t
20.ii.39	33° 53′ S.	137° 10′ E.	10	0	23·08	20·95	26·08
				10	23·24	20·98	26·08
				15	24·20	21·04	26·17

Some support for this explanation is offered by figures given in Table 1. These are taken from data of a cruise of the F.R.V. "Warreen". The station is almost on the same latitude as Moonta Bay, but nearer the opposite shore of the gulf. The warmer and more saline deep waters must have come from the north as stations at the entrance to the gulf worked on the same cruise, show lower chlorinities and temperatures at all depths and also a fall in both temperature chlorinity with increasing depth.

Port Wakefield (Fig. 7)

St. Vincent Gulf, near the head of which this station stands, terminates in a broad bay bordered with sand and mangrove flats which are exposed to a width of nearly a mile at half tide. A small channel has been dredged through this up to a wharf near the town, where the samples were taken. This channel has a length of about three-quarters of a mile. It is about thirty-four feet wide, and at an average high tide has a depth of about nine feet six inches, while at average low tides it has a depth of about two feet. It was last dredged during 1949-50. This carries away a part of the outflow of the Wakefield River, the main flow of which has now been diverted to run into the gulf a few miles north of the township. So it is only when the river is in spate that an appreci-

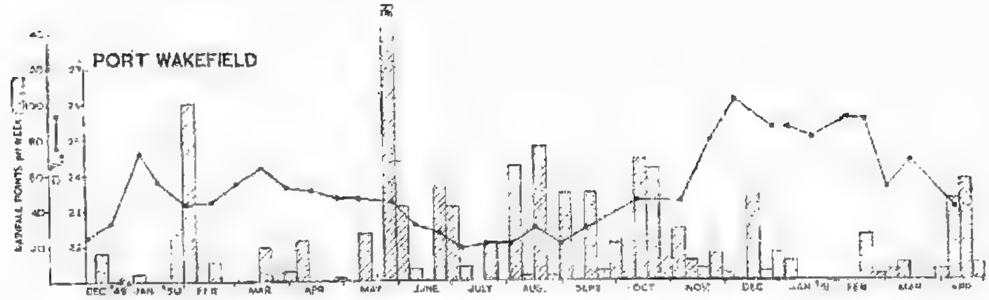


Fig. 7.—Surface chlorinities and rainfall at Port Wakefield, December 1949 to April 1951.

able amount of fresh water is discharged past the wharf where the samples were taken.

The position of this station near the head of St. Vincent Gulf coupled with an occasional inflow of fresh water from the Wakefield River, has resulted in giving this station a wider range of chlorinities than any other station with the exception of Victor Harbour. The highest figure recorded was 26·10 (December 8, 1950) and the lowest 21·95 (July 7, 1950). The annual evaporation at this station is estimated by Trumble (1948) as 79 inches and the annual rainfall is about 13 inches so, as at Port Augusta high evaporation, especially during the summer months, is a potent factor in the maintenance of high chlorinities. The lower values are the results of occasional dilution by the Wakefield River.

Brighton (Fig. 8)

This station occupies a position in St. Vincent Gulf more or less similar to that of Moonta Bay in Spencer Gulf, so the cycle of events at the two stations might well be compared. Actually, the range of chlorinities at Brighton was the smallest noted in this survey. The maximum value was 20·85 (December 12, 1950, January 19, and March 3, 1951) and the minimum 20·35 (June 4, 1950). Again the annual cycle of high summer and low winter chlorinities is not well marked, some of the winter readings falling only slightly short of many of the summer ones. So here again a flow of highly saline waters from the head of the gulf along its bed can be postulated. There is, however, no marked tidal turbulence indicated on the Admiralty charts in the vicinity of Brighton which would indicate mixing of bottom and surface waters as there is at Moonta Bay, but prevailing sou'westerly winds would affect this coastline as they would the eastern coastline of Spencer Gulf and influence its chlorinities as they do those at Moonta Bay.

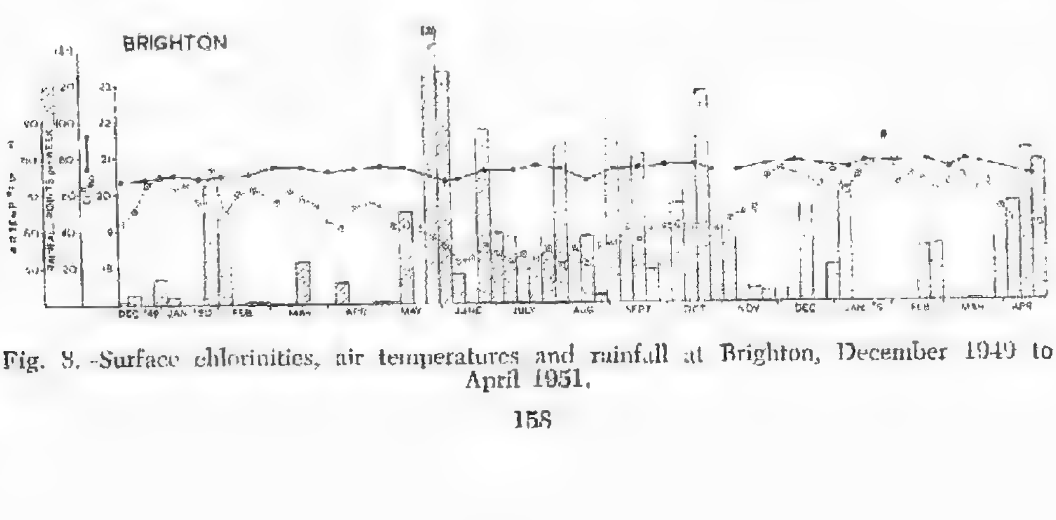


Fig. 8.—Surface chlorinities, air temperatures and rainfall at Brighton, December 1949 to April 1951.

TABLE 2.
Hydrographic data from sea-water samples taken at two stations in St. Vincent Gulf

Date	Station	Depth (m.)	Temp. (°C.)	Cl°/₀₀	δ_t
30/12/43	Off Glenelg	10	17·25	20·09	26·46
		20	17·50	20·18	26·53
		30	17·50	20·22	26·58
		40	17·50	20·24	26·61
30/12/43	Off Cape Jervis	10	19·50	20·49	26·44
		20	19·50	20·51	26·47
		30	19·50	20·56	26·57
30/1/44	Off Glenelg	10	20·00	20·47	26·29
		20	20·00	20·51	26·34
		30	20·25	20·42	26·15
		40	20·00	20·48	26·30
4/6/44	Off Glenelg	0	14·30	20·34	27·48
		10	14·50	20·40	27·53
		20	14·50	20·41	27·54
July '44	Off Glenelg	0	18·30	20·42	26·66
		10	18·20	20·44	26·71
		20	18·10	20·45	26·75
		30	18·20	20·48	26·77
		40	18·50	20·52	26·74
July '44	Off Cape Jervis	0	18·80	20·73	26·95
		10	18·50	20·70	26·99
		20	18·30	20·69	27·03
		30	18·30	20·69	27·03
6/8/44	Off Cape Jervis	0	12·20	20·65	28·35
		10	11·50	20·64	28·48
		20	11·50	20·67	28·52
16/9/44	Off Cape Jervis	0	13·30	20·44	27·83
		10	13·00	20·43	27·88
		20	13·00	20·43	27·88
		30	13·00	20·49	27·96
12/1/45	Off Glenelg	0	19·10	20·45	26·49
		10	18·50	20·42	26·60
		20	18·50	20·44	26·63
		30	18·50	20·44	26·63
		40	18·50	20·45	26·64
4/2/45	Off Cape Jervis	0	20·50	20·59	26·30
		10	20·20	20·60	26·41
		20	20·00	20·61	26·48
		30	20·00	20·60	26·46
21/10/45	Off Cape Jervis	0	15·25	20·31	27·27
		10	14·80	20·30	27·32
		20	14·80	20·31	27·34
		30	14·80	20·32	27·35
25/11/45	Off Glenelg	0	18·50	20·40	26·58
		10	17·00	20·40	26·95
		20	17·00	20·45	27·02
		30	17·00	20·44	27·01

Table 2 is compiled from samples of sea water collected during the war years and analysed by the Division of Fisheries of the C.S.I.R.O. Glenelg is a few miles north of Brighton, while Cape Jervis is the point of the mainland closest to Kangaroo Island (see Fig. 1). These figures show in general (i) that deeper waters have a higher chlorinity than surface waters, (ii) that the increase in chlorinity with depth is more marked off Glenelg than it is off Cape Jervis, and (iii) that the surface and bottom chlorinities off Cape Jervis are generally higher than are those off Glenelg. These points seem to indicate that the highly saline water from the bed of the gulf does become admixed with surface waters, but mainly some distance south of Glenelg. More information is, however, needed to verify these matters.

Chittleborough (unpublished data) records a maximum chlorinity of 21·21‰ and a minimum of 20·22‰ at Outer Harbour which is about sixteen miles north of Brighton. These values are in general, slightly higher than those at Brighton. This is in keeping with the position of his station further up the gulf. The wider range of chlorinities here can be accounted for by the influence of the Port "River", a long inlet, in which he records a wider range than at Outer Harbour, namely, a maximum of 20·89‰ and a minimum of 19.49‰.

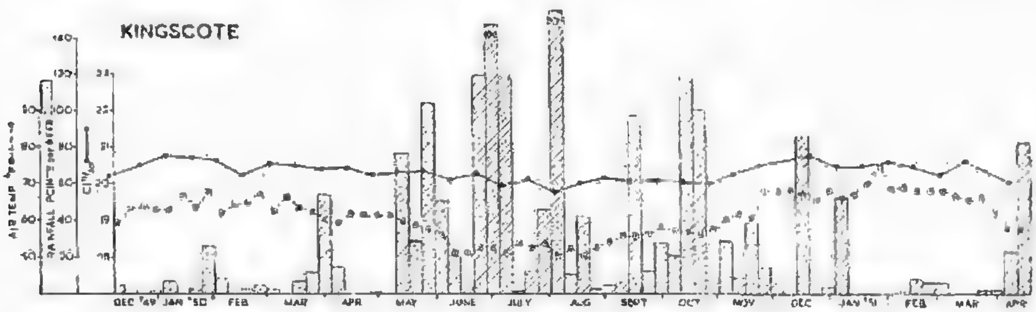


Fig. 9.—Surface chlorinities, air temperatures and rainfall at Kingscote, December 1949 to April 1951.

KINGSCOTE (Fig. 9)

This station is on the north coast of Kangaroo Island. Its jetty is in a wide, fairly shallow bay which is protected to the north and west by a sandy spit, mostly covered at high water but rising at intervals to form a chain of low islets. The maximum chlorinity recorded was 20·75 (January 6 and December 22, 1950) and the minimum 19·75 (August 4, 1950). There is a fairly well-marked cycle of high readings in summer and low in winter, showing the influence of a predominantly winter rainfall and a fairly high rate of evaporation in the summer months. According to Trumble (1948) the annual evaporation is 51·6 inches and mean annual rainfall 19·28 inches. The lowest winter figures are, however, still above the average for the more oceanic stations, such as Elliston and Robe, indicating that the highly saline waters of St. Vincent Gulf influence this station too. Womersley (1947) records slightly higher chlorinities on the north coast of Kangaroo Island than on the south coast which faces the Southern Ocean.

VICTOR HARBOUR (Fig. 10)

This station showed the widest range of chlorinities and also the lowest chlorinity encountered in this investigation. The highest reading was 20·20 (March 4, 1950) and the lowest 16·05 (August 5, 1950). The general run of chlorinities seems to lie between about 19·50 and 20·20, but there are sudden

drops to much lower figures. These drops are undoubtedly to be associated with the outflow of fresh water from the River Murray whose waters enter the sea about 15 miles almost due east of the station. The River Murray actually opens into a broad and shallow expanse of water which includes Lake Alexandrina and Lake Albert. On the seawards side of these lakes several islands, the remnants of a former sand dune system, break up the flow of water into several channels which again converge on to a single opening to the sea between sand dunes which is known as Murray Mouth. In 1940, a series of barrages was completed linking these islands so that the outflow of freshwater could be controlled and the inflow of sea water prevented. The lakes which were originally very brackish have thus by now become virtually freshwater lakes. Before the building of the barrages the chlorinity of the lakes was in the vicinity of 4·0, but since their establishment this figure has dropped to about 0·06 (McIntosh, 1948).

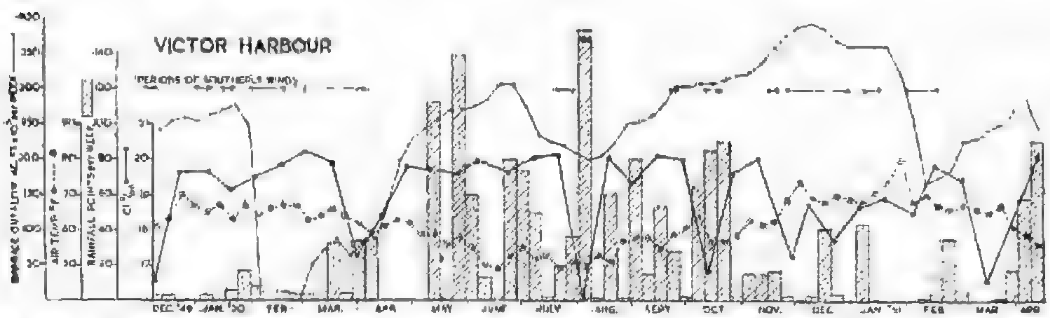


Fig. 10.—Surface chlorinities, air temperatures, rainfall and periods of moderate to strong southerly winds (full line indicates almost continuous southerlies, broken line, intermittent southerlies), at Victor Harbour and estimated outflow from the River Murray, December 1949-April 1951.

The approximate outflow of freshwater through the barrages is shown in Figure 10. These figures are computed from the weekly flow of water over Lock 1 in the river at Blanchetown about 170 miles upstream from the mouth. It is estimated that the river water takes about ten days to flow from Lock 1 to Lake Alexandrina, so this lag has been allowed for in plotting the points. A small percentage which would be lost by evaporation during this period has been ignored.

The influence of this outflow is noted at Victor Harbour only during periods of southerly winds. When the wind is in other quarters the chlorinities at this station are generally high, more or less on a par with conditions at Robe and Port Elliston on the open coastline. The marked influence of southerly winds can be explained by the delineation of the coastline (see Fig. 1) and by the ocean currents along it. The great sub-antarctic West Wind Drift is partly deflected northwards when it strikes western Tasmania. This portion flows north-west along the south-eastern coast of the State to form a large eddy whose northernmost boundary is the south coast of the Australian Continent. This eddy would thus tend to carry outflowing water from Murray Mouth towards Victor Harbour. Inshore, however, the current would be relatively weak so that effective transport of surface water would be apparent only when it was assisted by a moderate or strong southerly wind component. Westerly or northerly components would counteract it while easterly winds in this region are relatively rarer and of lower velocity so would be less effective. Periods of moderate to strong southerly winds are indicated in Figure 10 and these correspond almost without exception with falls in chlorinity. The noteworthy exception is during February, 1950, when despite almost continuously southerly

winds the chlorinity rose. During this period, however, the barrages were closed and the small flow over Lock 1 was allowed to fill Lake Alexandrina. During the remainder of the period of this investigation, the barrages have been closed for no more than a few odd days. From late November 1950 to early February 1951 there was an unusually high outflow from the barrages and there were many periods of southerly winds. These factors account for the low and fluctuating chlorinities during these months. The lowest chlorinity recorded (16·05) on August 5, 1950, was at a time of very high rainfall (the highest weekly record for the year), moderate outflow from the barrages and a week of continuous south to sou'westerly winds.

Two small rivers, the Hindmarsh and the Inman, enter the sea near Victor Harbour. They flow freely only after heavy rain. No direct correlation was found between their outflow and the chlorinities recorded at the sampling station with the possible exceptions of the samples taken on August 5, 1950 (Cl‰ = 16·05) and October 14, 1950 (Cl‰ = 16·80).

Robe (Fig. 11)

The jetty at this station is in a wide, fairly deep and well ventilated bay. The highest chlorinity was 20·15 (January 22, 1950, and January 18, 1951) and the lowest 19·00 (August 18, 1951). The four low figures during July and August are to be associated with heavy rains at about the time of collections. The mean annual rainfall is given by Trumble (1948) at 24·75 inches and the

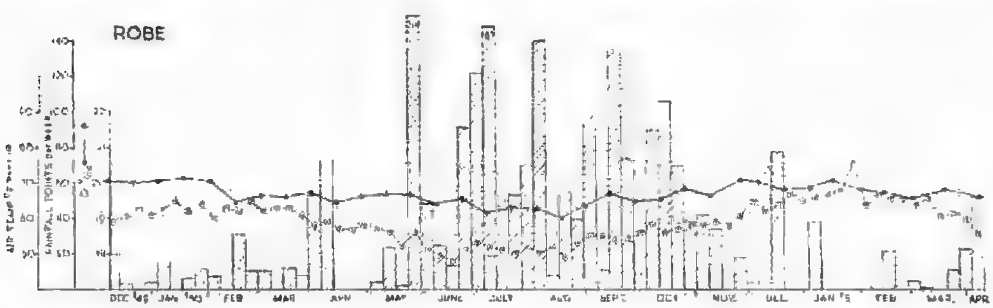


Fig. 11.—Surface chlorinities, air temperatures and rainfall at Robe, December 1949 to April 1951.

annual evaporation as 37·4 inches. Even though there are no significant streams or rivers entering the sea in this region the porous tertiary limestone of the district allows an outflow of subterranean freshwater. The relatively high mean annual rainfall and low evaporation rate would thus give this station generally lower chlorinities than the other stations which have been discussed. The highest figures, during the summer months, are comparable with the maxima of Victor Harbour and of Port Elliston, the only other two stations, excepting Streaky Bay, which are not affected by gulf waters. The annual cycle of high summer and low winter readings is well marked. It follows fairly closely the annual air temperature cycle.

DISCUSSION

The fluctuation in chlorinities of seawater in the vicinity of coastlines must be greater than is the case in surface waters of the open ocean. Inflow of freshwater, either by precipitation or from rivers and evaporation in shallows, will depress or elevate the values respectively. Gilles (1949) records an annual periodicity at some surface sampling stations in the Irish Sea in an analysis of water samples taken between 1935 and 1946. Several of these stations (e.g.

Liverpool Bar and Morecambe Bay) show summer maxima and winter minima while one station, midway between Holyhead on the Welsh coast and Kish near the Irish coast, shows a winter maximum and summer minimum. These fluctuations seem to be the result of two major factors, namely, freshwater inflow from adjacent rivers and inflow of Atlantic water. Bigelow and Leslie (1930, p. 452) also record a seasonal fluctuation in the salinity of surface waters in Monterey Bay, California, with low values in February to April, and high in June to August. This they correlate with the seasonal variation in discharge of the Salinas and other rivers which reach a maximum in November, December and January.

Where the freshwater inflow is considerable, as in an estuary, stratification will occur, the position and integrity of the boundary depending on (a) the amount of inflow, (b) the degree of tidal turbulence, (c) evaporation, and (d) the configuration of the shore line and bottom (e.g. Rochford, 1951). The actual chlorinity figure in any given locality will depend on these same four factors, so that in a region of low rainfall and high evaporation, the coastal values will be higher than those of adjacent oceanic waters, the difference depending on the amount of evaporation and influx of oceanic water.

Wust (1936) cited by Sverdrup *et al.* (1942, p. 124) estimates the region of the highest surface salinity and evaporation in the open oceans of the Southern Hemisphere to lie between lat. 20° and 30°S. He gives an average figure of about S‰ = 35·75 (Cl‰ = 19·83) and annual evaporation-minus-precipitation figure of about 30 inches. Port Augusta (lat. 32° 28′S) and Port Wakefield (lat. 34° 11′S) fall just outside this range. In these two places, however, and in the gulfs generally, chlorinities are much increased by the high evaporation rate due to proximity to the arid interior of the continent and the very low freshwater inflow either from rainfall or streams.

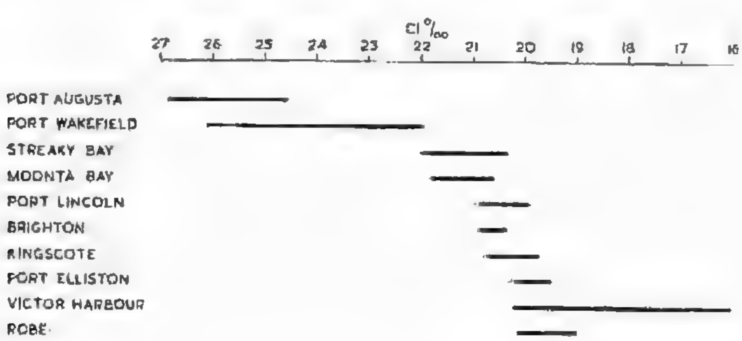


Fig. 12.—Ranges of chlorinities at the ten stations December 1949 (except Port Elliston, March 1950) to April 1951 arranged in order of maximum chlorinities.

In Figure 12 are shown the ranges in chlorinities at the ten stations during the period of the investigation. They are listed in order of the highest chlorinity recorded. The stations fall thus into natural groups. The two heading the list, Port Augusta and Port Wakefield, with high and fluctuating chlorinities, are at the heads of the two gulfs. Streaky Bay falls far behind these and shows clearly the effect of local evaporation with moderate ventilation by oceanic waters. Moonta Bay, about halfway up Spencer Gulf, is intermediate between Port Augusta and Port Wakefield on the one hand, and the stations nearer the entrances to the gulfs, namely, Brighton, Port Lincoln and Kingscote, on the other. The smaller fluctuation at Moonta Bay compared with Port Augusta

and Port Wakefield has already been discussed. A comparison of the results from Moonta Bay with those of Port Wakefield shows clearly the influence of lack of circulation in upper gulf waters. The two stations are on approximately the same latitude and their respective evaporation-minus-precipitation figures are about the same, approximately 61 and 66 inches respectively according to Trumble (1948). Yet as can be seen from Figure 13, their average chlorinities and chlorinity ranges are widely divergent. The next three stations, Brighton, Port Lincoln and Kingscote, are obviously influenced by the highly saline gulf waters, Kingscote, because of its position to a lesser extent than the other two. The small range at Brighton has also been discussed. The three remaining stations have similar maxima showing that these, all on the open coast, are the nearest to purely oceanic conditions. Their ranges are influenced by local conditions. Port Elliston, in its well-ventilated bay, has a small range; Robe has its range extended by relatively heavy rainfall in the winter season, while Victor Harbour is very strongly influenced by outflow from the River Murray barrages.

TABLE 3.

Surface stations worked in the Great Australian Bight and St. Vincent Gulf by the B.A.N.Z.A.R. Expedition. March-April 1930.

No.	Date	Time (h. m.)	Lat. (S° ′)		Long. (E° ′)		Temp. (°C.)	$S^0/_{00}$	$Cl^0/_{00}$	P_2O_5 (mg. l.)
1	March 27	24·00	35	34	129	19	18·72	35·53	19·65	4
2	March 28	12·05	35	33	130	12	18·57	35·59	19·69	2
3	March 28	24·00	35	26	131	48	18·10	35·35	19·55	3
4	March 29	12·00	35	20	133	22	19·24	35·56	19·67	1
5	March 29	24·00	35	23	134	42	18·39	35·53	19·65	0
6	March 30	12·10	35	28	136	02	17·37	35·84	19·83	0
7	March 30	21·00	35	28	137	13	18·57	36·04	19·93	0
8	March 31	12·10	35	24	137	53	18·55	36·03	19·93	0
9	April 1	00·10	34	55	138	19	20·08	37·11	20·69	0

The extremely high chlorinity values recorded in northern gulf waters seem to be unique. The highest value recorded by Thompson (1939) for the Red Sea is $Cl^0/_{00} = 22 \cdot 78$ ($S^0/_{00} = 41 \cdot 05$) in deep water at the northern end. Sverdrup *et al.* (1942, Chart VI) shows a $S^0/_{00} = 40 \cdot 00$ ($Cl^0/_{00} = 22 \cdot 19$) isohaline near the eastern shore of the Persian Gulf, salinities in other parts of the gulf presumably being lowered by inflow of water from the Rivers Tigris and Euphrates. Indeed, most gulfs in most parts of the world have considerable river inflows which depress their chlorinity values and make them estuarine.

Conditions in the Spencer and St. Vincent Gulfs are then in some ways the reverse of those found in an estuary. Towards their heads, there is an increase in chlorinity, but as in an estuary, results obtained from hydrological data collected by the F.R.V. "Warreen" already cited, show that there is an increase in chlorinity with depth. The rising tide must then flow into the gulfs on the surface, overlying the deeper, more saline water. In a typical estuary (e.g. Rochford, 1951) incoming oceanic water will flow in along the bottom while the lighter, fresher water will move out at the surface. Further systematic hydrological work will be necessary to verify this point in the gulfs.

Some verification of the results of the present workers as to the chlorinities within the gulfs has been obtained from the hydrological data of cruises of the

F.R.V. "Warreen" already referred to, and also from hydrological data from the B.A.N.Z.A.R. Expedition (Howard, 1940). Nine surface stations worked on this expedition have been numbered 1 to 9 on Figure 1 for the convenience of this paper and are listed in Table 3. These chlorinities remaining relatively stable across the Great Australian Bight show a rise at Station 6, opposite the mouth of Spencer Gulf, and a further rise in Investigator Strait, north of Kangaroo Island at Stations 7 and 8, and still further a rise at Station 9, which is at the Semaphore Anchorage, about 14 miles north of Brighton.

A noteworthy feature of these figures, too, is the total absence of phosphate in St. Vincent Gulf and adjacent waters. Attempts at estimations of phosphate in samples received during the present survey have been made by one of us (S.J.E.). It was found impracticable, however, to maintain this line of investigation because of the inevitable delay between the collection of the samples and their arrival at the laboratory. All estimations made, however, showed remarkably low phosphate concentrations, but these are in keeping with the B.A.N.Z.A.R. Expedition results (Table 3), and also with those of Womersley (1947).

ACKNOWLEDGMENTS

The authors are deeply indebted to the following people who have so faithfully collected the samples of seawater for them, Miss Robin Fleming and Miss Louise Lucas of Streaky Bay; Mr. M. R. Baum and Mr. Neville Owen of Port Elliston; Mr. Maurice Guy and Mr. C. W. Johnston of Port Lincoln; Mr. Malcolm Cockburn of Port Augusta; Mr. Don Tossell of Moonta Bay; Mr. Max Tregilgas of Port Wakefield; Mr. Robert Menz of Kingscote, Mr. Graham Field of Victor Harbour, Mr. F. E. Bumball, Mr. J. F. Price, Mr. H. F. Heidrich, and Mr. M. J. M. Keough of Robe.

Acknowledgment is also made to Mr. B. Mason and other members of the staff of the Commonwealth Meteorological Bureau, Adelaide; to Lieut.-Col. H. C. Tolley, and members of the Staff of the Engineering and Water Supply Department, Adelaide; and to Mr. W. R. Tuck of the South Australian Harbours Board. These gentlemen have given us much useful information from their files and valuable opinions from their experience.

The Division of Fisheries, C.S.I.R.O., has kindly provided standard seawater and some hitherto unpublished data from their records of chlorinities in South Australian waters.

The District Clerk of Port Wakefield has provided local information about the flow of water in the Wakefield River and about the condition of the shipping channel up to that port.

The work has been largely financed by the State and Commonwealth Research Grants.

REFERENCES

Bigelow, H. B., and Leslie, M., 1930. Reconnaissance of the waters and plankton of Monterey Bay, July, 1928, Bull. Mus. Comp. Zool. Harvard Coll. 70: 429-581.

Commonwealth Scientific and Industrial Research Organization, 1951. Oceanographic Station List. Vol. 1. Hydrological and Planktological Observations by F.R.V. "Warreen" in South-Eastern Australian Waters, 1938-9.

Gilles, D. C., 1933. The Temperature and Salinity of the Surface Waters of the Irish Sea for the period 1935-46. Mon. Not. R. astr. Soc. Geophys. Suppl. 5: 374-97.

Howard, A., 1940. Programme of work and record of observations, B.A.N.Z.A.R. Exp. Rep., Ser. A, 3: 29-85.

McIntosh, Hon. M., 1948. The River Murray Barrages, J. Agric. S. Aust., 52: 425-9.

Rochford, D., 1951. Studies in Australian Estuarine Hydrology. I. Introductory and Comparative features, Aust. J. Mar. Freshw. Res. 2: 1-116.

Sverdrup, H. U., Johnson, M. W., and Fleming, R. H., 1942. "The Oceans." (Prentice-Hall Inc.: New York.)

THOMAS, I. M., and EDMONDS, S. J., 1953. Surface Chlorinity Observations in South Australian Coastal Waters, December 1949-April 1951, Commonwealth Scientific and Industrial Research Organization, Oceanographic Station List **14**: 53-64.

THOMPSON, E. F., 1939. Chemical and Physical Investigations—the General Hydrography of the Red Sea, John Murray Exped. 1933-34, Sci. Rept. **2**: 83-103.

TRUMBLE, H. C., 1948. Rainfall, evaporation and drought frequency in South Australia, J. Agric. S. Aust. **52**: 55-64.

WOMERSLEY, H. B. S., 1947. The marine algae of Kangaroo Island. A general account of the algal ecology, Trans. Roy. Soc. S. Aust. **71** (2): 228-52.

SACCOGLOSSUS APANTESIS, A NEW SPECIES OF ENTEROPNEUST FROM SOUTH AUSTRALIA

BY I. M. THOMAS

Summary

A new species of the enteropneust genus *Saccoglossus* is described and named *Saccoglossus apantesis.* This is the first record of this genus in Australia and the first enteropneust to be described from South Australia.

SACCOGLOSSUS APANTESIS, A NEW SPECIES OF ENTEROPNEUST FROM SOUTH AUSTRALIA

By I. M. THOMAS*

[Read 10 Nov. 1955]

SUMMARY

A new species of the enteropneust genus *Saccoglossus* is described and named *Saccoglossus apantesis*. This is the first record of this genus in Australia and the first enteropneust to be described from South Australia.

I. INTRODUCTION

Enteropneusts already recorded from the Australian continent include *Balanoglossus australiensis* (Hill) found near Sydney (Hill, 1894); *Ptychodera flava Escholtz* (= *Pt. pelsarti*), from the Abrolhos Islands (Dakin, 1916), and *P. flava* and *B. carnosus* (Willey) from the Great Barrier Reef (Trewavas, 1931). Trewavas also described a number of tornaria larvae from the same region which have not yet been associated with specific adults. The present author has identified a single specimen sent to him from the Great Barrier Reef as *Glossobalanus hedleyi* (Hill) first described from Funafuti (Hill, 1897). In 1899 Benham described *Saccoglossus otagoensis* (Benham) from Otago Harbour, New Zealand.

The form to be described herein is found on the shores of Encounter Bay, South Australia (lat. 35° 35′ South, long. 138° 36′ East) about fifty miles due south of Adelaide. The foreshore in this region consists of an extensive platform of a sandy Permian fluvioglacial stratum. The platform extends about one hundred yards offshore, sloping gradually seawards and dropping abruptly into deeper water at its outer edge. It is largely overlaid by a deposit of coarse sand, shell grit and some mud, which supports a thick growth of *Posidonia*, *Cymodocea* and *Zostera*. The first two of these plants cover most of the platform, whilst the latter is found in shallow water near its shorewards edge. Here the rock surface is pitted and dented to form basin-shaped depressions where the soil may lie to a depth of six to twelve inches, though in much of the area investigated the soil is no more than half this depth. This part of the coast is protected in part, to the west by Rosetta Head ("The Bluff") and offshore, to the south, by Wright Island, about half a mile away. Both these are granitic outcrops. The region is thus normally one of more or less quiet water.

The animals are found in the upper two or three inches of soil which is lightly bonded by *Zostera* roots. They have not as yet been found other than in association with this plant. Other animals found in the same habitat include Maldanid and other polychaete worms, some burrowing crustacea (*Callianasa ceramica* and *Crangon novozelandiae*), several burrowing lamellibranchs and occasional sipunculids and nemertines. The enteropneusts are extremely localised in their distribution. Although a considerable area of the foreshore has been examined by digging and sieving, they have been found only in three small regions, each not more than two square yards in extent and all about the same distance from high water mark. The regions are exposed at very low spring tides. The restricted distribution of the animals might be accounted for by

* Department of Zoology, University of Adelaide.

the pitted nature of the underlying rock which might tend to limit their lateral movements. In these regions, however, several specimens can be turned up in a single spadeful of soil. The animals are frequently so tangled in with the *Zostera* root-systems that it is almost impossible to obtain complete specimens. The abdominal region in particular is very fragile and breaks off readily. Brambell and Cole (1939a) have recorded that it is impossible to obtain intact specimens of *Saccoglossus cambrensis* because of its fragility.

A single specimen has been found in a similar habitat at Salt Creek near Edithburg on the eastern coast of Yorke Peninsula. Though this example was not sectioned, it bore all the external characteristics of the Encounter Bay specimens. Salt Creek is, in a direct line, about sixty miles north-west of Encounter Bay so it is likely that further investigation of suitable localities may show the animal to have a wide distribution along the South Australian coastline.

When the water is very still, casts can be seen on the sand surface which are similar to those produced by *S. cambrensis* (Brambell and Cole, 1939a). They are in the form of fine coils of sandy material bonded together by mucus. They are about a centimetre in diameter and one to one and a half turns in length and very fragile. No tubes have been observed though, if present and fragile, as are the castings, they would be no doubt shattered among the *Zostera* roots in the process of digging and sieving.

The following features place the animals in the family *Harrimaniidae* Spengel: (a) lack of hepatic diverticula, (b) lack of synapticulae, (c) lack of lateral septa, and (d) lack of circular muscles in the trunk region. They agree with the diagnosis of the genus *Saccoglossus* Schimkewitsch (= *Dolichoglossus* Spengel) in the following points: (a) proboscis very long, (b) collar about as long as broad, (c) lateral genital ridges present but no dorsal gonads, (d) gonads overlap the genital region to some extent, and (e) gill pores small but distinct. The specimens differ in several points from the published descriptions of the fourteen other species of the genus, so it is proposed to erect a new species, *Saccoglossus apantesis*, to include them. The specific name is derived from the Greek word meaning a meeting or an encounter, as it was near the place where the animals were first found that there occurred the historic encounter between Matthew Flinders in the "Investigator" and Nicolas Baudin in the "Geographe" in April, 1802.

Several detailed accounts of the anatomy of different species of the genus are available apart from the compendium of van der Horst (1927-39), for example, *S. otagoensis* by Benham (1899); *S. inhacensis* by Kapelus (1936); *S. cambrensis* by Brambell and Cole (1939a), and *S. horsti* by Brambell and Goodheart (1941). In the description of the present species then, only those features which are characteristic of *S. apantesis* will be dealt with. Features which it shares with several other members of the genus will, in the main, be omitted.

II. EXTERNAL FEATURES

S. apantesis is a moderately sized species. An adult in the living condition has a length of 70 to 85 mm. This is made up as follows: proboscis 20 to 25 mm.; collar 3·0 to 3·5 mm.; branchial region 10 to 12 mm.; genital region 15 to 20 mm. (the two latter regions overlap to a considerable extent); abdominal region 25 to 30 mm. The genital region in mature specimens is always coiled so that the measurements given for this region can be no more than an estimate.

Young specimens are coloured a uniform light orange. Adults have a proboscis of light orange, darkening somewhat at the base and stalk. The collar is orange-red with, in larger specimens, a white ring near the posterior margin. The branchial region is paler than the collar though darker than the proboscis. In females the genital ridges are light orange, but in males they are browny red. The lateral and ventral body walls in the genital region are similar in colour

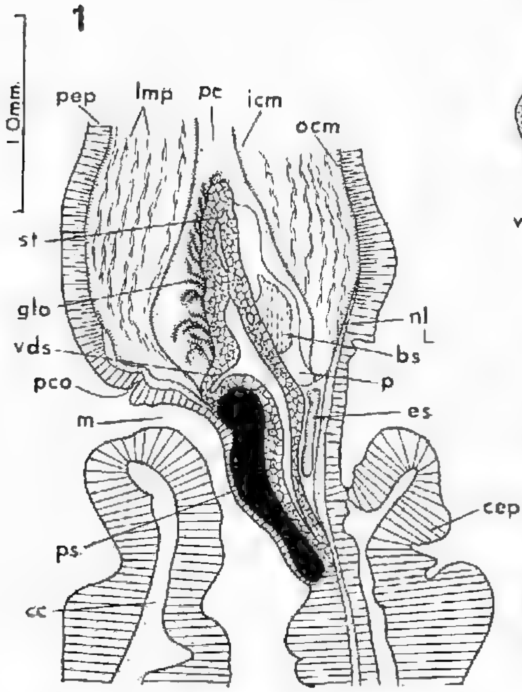
to the branchial region. The abdominal region is pale yellow-grey and translucent so that its enclosed sand grains and grit show readily through. No spotting or flecking with colour such as has been described in some other members of the genus is present.

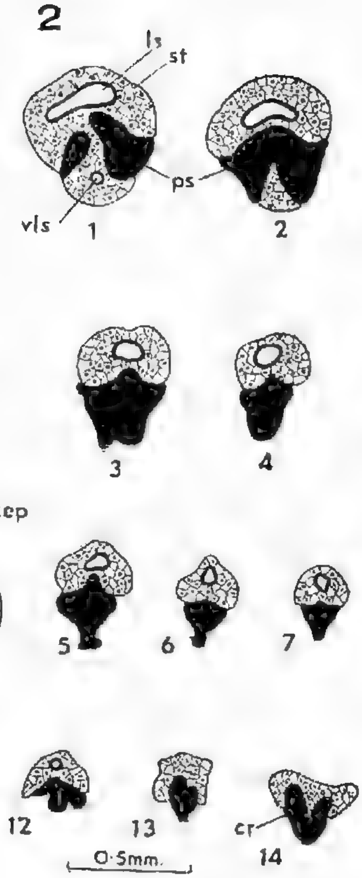
The proboscis, in the extended condition, tapers from its base to its tip, the tip being about half the diameter of the base. In contracted specimens it is cylindrical. There is only a very slight indication of a dorsal groove in the posterior quarter or so of its length and this is better seen in preserved and contracted material than it is in living specimens. There is no sign of a ventral proboscis groove. Occasionally the proboscis may show one or more deep, circular constrictions at varying positions along its length. These are caused by strong local contractions of the circular muscles. If a specimen is roughly treated while the proboscis is in this condition, the organ may break at these points. Autotomy of this kind must occur in natural conditions as very occasional specimens have been found with short probosces showing signs of terminal regeneration.

At the base of the proboscis is the pre-oral ciliary organ whose structure and significance have been described for *S. cambrensis* and some other forms by Brambell and Cole (1939b). As in the Welsh species, it takes the form of a horse-shoe-shaped groove, slightly dilated at its free dorso-lateral ends and partially surrounding the base of the proboscis where it tapers to form the stalk. The organ is not distinctively coloured as it is in *S. cambrensis* and therein resembles more the condition in *S. horsti* (Brambell and Goodheart, 1941).

The neck which unites the proboscis to the collar is, as is the case in other members of the genus, very slender. It bears on its left side the single proboscis pore which enable the end sac (Fig. 1), and thus the left dorsal coelomic pouch of the proboscis, to communicate with the exterior. The collar is slightly longer dorsally than it is ventrally and is somewhat flared anteriorly. The posterior border is slightly flared also and at the base of this flare there is a conspicuous circular groove corresponding in position to the white ring mentioned earlier. This groove and white ring are best seen in mature specimens. The posterior flare overlaps the first two or three gill pores.

The branchial region possesses thirty to forty-five pairs of gill pores on its dorsal surface. The number apparently increases with increasing size of the animals. The anterior ones are small and almost circular. They increase in size to about the sixth pair of the series and become elliptical laterally. The final seven or eight become rapidly smaller and more circular in form, the ultimate ones frequently being difficult to discern externally. The latter part of the branchial region is overlapped by the genital region, the first genital pouch appearing usually at about the level of the twentieth pair of gill pores. It is noticeable that in less mature specimens, that is, those with a smaller number of gill pores and less well-developed gonads, the proportion of gill clefts in front of the first genital pouch is higher than it is in more mature specimens. This may be due to the combined effect of an increase in the number of branchial pores posteriorly and an anterior penetration of the gonads with increasing maturity. In mature specimens, the gonads form conspicuous dorso lateral genital ridges which, in their region of maximal development, that is, in the posterior branchial and oesophageal regions, comprise about two-thirds of the animal's total body width (Fig. 8). The ridges begin to decrease gradually in size in the posterior oesophageal region and disappear in the anterior abdominal region. The increase in bulk of the genital ridges with growth of the animals to maturity leads to a considerable coiling in this part. Between the gill clefts, and farther back between the genital ridges, a slight medio-dorsal elevation of the epidermis overlies the dorsal nerve cord (Fig. 4). This ridge is less evident in the abdominal region.





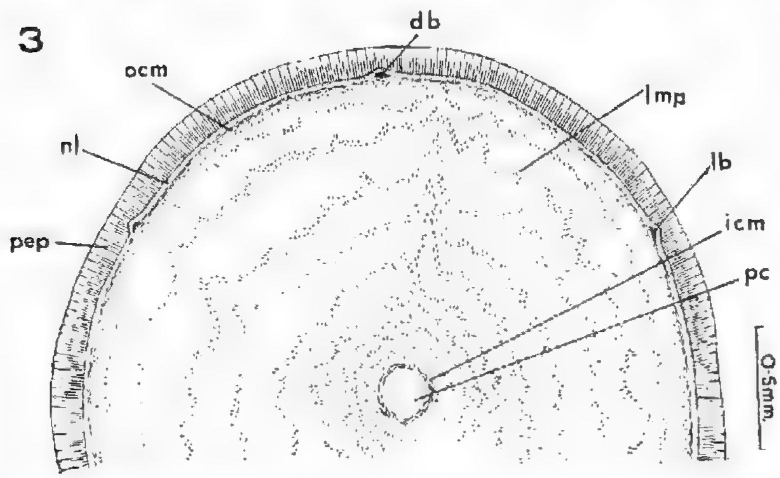


Fig. 1.—Longitudinal sagittal section of the base of the proboscis. bs., blood sinus; cc., collar coelom; cep., collar epidermis; es., end sac; glo., glomerulus; icm., inner circular muscle layer of proboscis; lmp., longitudinal muscles of proboscis; m., mouth; nl., nerve layer; ocm., outer circular muscle layer of proboscis; p., pericardium; pc., proboscis coelom; pco., pre-oral ciliary organ; pep., proboscis epithelium; ps., proboscis skeleton; st., stomochord; vds., ventral diverticulum of stomochord.

Fig. 2.—1 to 14, Serial sections of stomochord and proboscis skeleton at about 0·05 mm. intervals. cr., crura of proboscis skeleton; ls., lumen of stomochord; vls., lumen of ventral diverticulum of stomochord; other guide letters as in previous figure.

Fig. 3.—Transverse section of proboscis. db., dorsal bloodvessel of proboscis; lb., lateral blood vessel; other guide letters as in previous figures.

About two millimetres behind the last pair of gill pores the paired intestinal pores can be seen on the dorsal surface. They form two rows (Figs. 7 and 8), one on each side of the mid-dorsal line which diverge at an angle of thirty-five to forty degrees from the mid-line. Six to eight apertures appear on each side. In *S. kowalevskyi* (van der Horst, 1927-39) it is reported that the posterior of the four to six pairs of pores present are further from the mid-line than are the anterior ones. Through the kindness of Prof. F. W. Rogers Brambell, the author has been able to examine some specimens of *S. cambrensis.* In these, the five to seven pairs of patent pores form lines parallel to the mid dorsal line. A similar condition obtains in *S. inhacensis* (Kapelus, 1936). No descriptions of the external appearance of the intestinal pores seem to be available for other members of the genus.

Ventrally, in the trunk region, the main longitudinal musculature of the body is readily identifiable by its fine transverse striations. In the anterior branchial region, this musculature, though thicker in the ventral region, extends upwards in the lateral body walls nearly to the level of the gill pores (Fig. 4). Farther back, it becomes more concentrated ventrally so that at the posterior end of the branchial region and in the oesophageal region (Fig. 8) it forms two conspicuous ventro-lateral ridges which taper away towards the end of the genital region but are still visible in the abdominal region (Fig. 5). The ventral nerve cord can be seen medially between the lateral muscle masses throughout the length of the trunk.

The width of the intestinal region of a freshly caught specimen is, near its anterior end, little more than half that of the genital region even though it may be distended by its content of sand and shell-grit. It tapers gradually to about half this width near its posterior extremity. The ventral longitudinal muscle ridges, though diminishing in size, are visible throughout its length.

The epidermis of the trunk region is mainly glandular and can be divided into three different types. That in the vicinity of the gill pores is smooth and similar to that described for *S. cambrensis* and *S. horsti.* That covering the ventral and (in the anterior branchial region) lateral longitudinal muscle bands has fine transverse elevations which have already been noted above; while that on the remainder of the dorsal surface, on the genital ridges and on the lateral body walls, is raised into small, transversely arranged elliptical eminences (Figs. 5 and 7).

III. INTERNAL ANATOMY

The epidermis of the proboscis is between 0·1 and 0·2 mm. thick (Figs. 1 and 3). The nerve layer which lies immediately under it shows a slight dorsal thickening which, however, is much less well developed than is the corresponding structure in *S. cambrensis* and *S. horsti.* This may be associated with the slighter development of the dorsal groove of the proboscis in *S. apantesis.* The dorsal (subneural), the two lateral and the ventral blood vessels lie between the nerve layer and the outer layer of circular muscles. The latter is about equal in thickness to the nerve layer and must be capable of very forceful contractions as is indicated by its ability to autotomise portions of the proboscis. The main bulk of the proboscis tissues is made up of longitudinal muscle fibres which are arranged in concentric rings, each ring being separated from its neighbours by a layer of loose connective tissue. At least nine or ten of these rings are apparent in all specimens examined (Fig. 3) and occasionally there are indications of an eleventh incomplete ring represented by a number of scattered longitudinal fibres which lie close to the inner layer of circular muscle fibre which line the proboscis coelom. Seven to ten such concentric rings have been described in *S. mereskowskii* and nine or more in *S. horsti.* Towards the posterior end of the proboscis, the inner rings become indistinct and disappear so that at the level of the anterior extremity of the proboscis complex, only five or six of them are readily apparent. The proboscis coelom extends nearly to

the anterior extremity of the organ. The glomerulus (Fig. 1) surrounds the anterior extremity of the stomochord but farther back it is found only ventrally and laterally to the stomochord.

The stomochord is fairly straight and bluntly rounded anteriorly. In much contracted specimens, however, it may be considerably buckled dorso-ventrally. It has a well-developed ventral diverticulum (Fig. 1) which is supported by the bifid tip of the proboscis skeleton (Fig. 2 (1)). The short, blunt prongs coalesce dorsally so that a ventral groove is formed in the skeleton (Fig. 2 (2) and (3)) in which lies the backwardly directed tip of the ventral diverticulum. The body of the skeleton narrows to become quite slender in its mid-region but mid dorsally in its anterior part it bears a distinct ridge which penetrates the body of the stomochord (which lies immediately above it) in its mid-ventral line (Fig. 2 (3), (4) and (5)). In the hinder part of the body of the skeleton, lateral wings are slightly developed (Fig. 2 (11) and (12)), but these disappear before the skeleton bifurcates to form the crura (Fig. 2 (14)). The crura pass upwards, one on each side of the junction of the stomochord with the lining of the buccal cavity and then arch outwards, backwards and downwards in the wall of the buccal cavity. They extend about halfway along the length of the collar and embrace slightly more than half of the circumference of the buccal cavity. The proboscis skeleton has no hard, central concretions such as occur in some specimens of *S. cambrensis*, nor have such concretions been noted in the branchial skeleton.

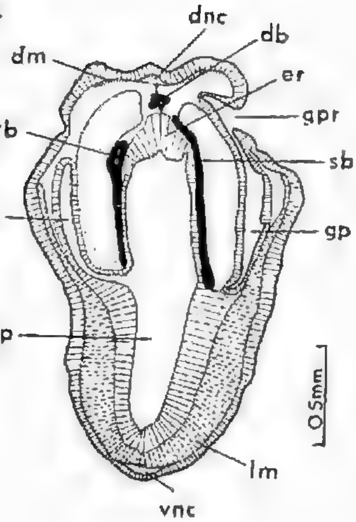
Spengel (1893) recognised five transverse zones in the collar epidermis of enteropneusts, each zone being characterised by certain cell structures and staining propensities. In *S. apantesis* all five zones are clearly distinguishable (Fig. 6). The first, the anteriormost, is a fairly low epithelium of ciliated cells which stain lightly with Ehrlich's haematoxylin. This zone covers the anterior flange of the collar. The second zone, which is nearly as broad as the other four put together, contains much material which stains heavily with haematoxylin. Anteriorly, where it abuts on the first zone, its cells are low but they increase in height in the middle region to shorten again towards the hinder margin. Near its anterior margin there is a circular furrow whose depth varies considerably in relation to the degree of longitudinal contraction of the collar. The third zone consists of narrow, elongate cells in which material which stains heavily is concentrated towards their bases. This material does not stain quite as heavily as does that of the second zone. The fourth zone is the narrowest and forms the white line on the collar referred to previously. It bears a deep furrow and its cells contain relatively few deeply-staining particles towards their bases. The fifth zone, like the first, is ciliated but forms a much higher epithelium. It forms the posterior flange of the collar which overhangs the beginning of the branchial region.

The general arrangement of these zones is similar to that in *S. carnbaicus* (van der Horst, 1927-39) and *S. kowalevskii* (Agassiz). In both these species the five zones are distinguishable. In *S. cambrensis*, the third and fourth zones are not readily distinguishable while in *S. horsti* they are indistinguishable. In *S. inhacensis* (Kapelus, 1936) none of the five zones is clearly demarcated.

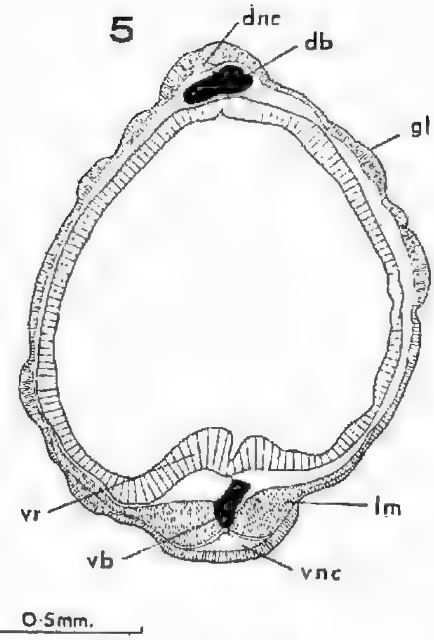
The number of pairs of gill pores varies between thirty and forty-five. This number is less than is found in most other members of the genus. *S. gurneyi* approaches it most closely with forty to sixty pairs. The number of pairs of gill pores in the remaining species are given in the list of distinguishing features of the different species at the end of this article. The detailed histology of the branchial region shows no special distinguishing features. In transverse section the branchial portion of the pharynx is seen to be about equal in extent to the non-branchial (food-groove) portion (Fig. 4).

The first genital pouch appears in about the mid-branchial region. Mature oocytes (measured on fixed material) are about 310 μ long and about 285 μ

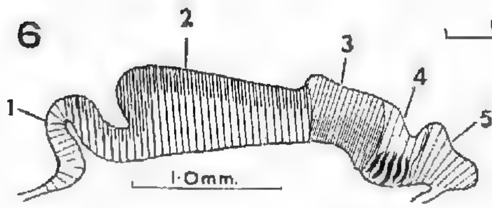
4



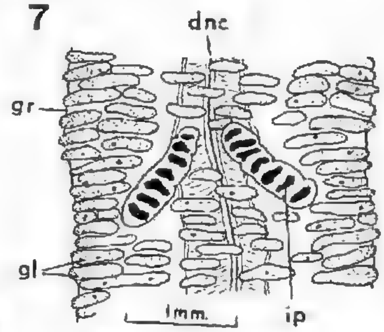
5



6



7



8

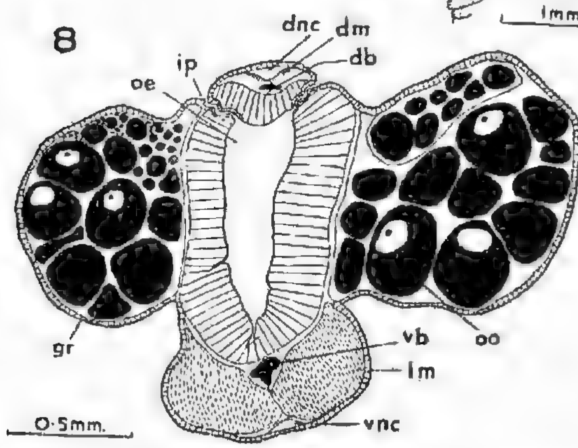


Fig. 4.—Transverse section in branchial region. db., dorsal bloodvessel; dm., dorsal longitudinal muscle of trunk; dnc., dorsal nerve cord; er., epibranchial ridge; gp., gill pouch; gpr., gill pore; lm., longitudinal muscles of trunk; nbp., non-branchial portion of pharynx; sb., skeleton of gill septum; tb., skeleton of gill tongue; vnc., ventral nerve cord.

Fig. 5.—Transverse section of abdominal region. gl., glandular eminence; vb., ventral bloodvessel; vr., ventral ridge in gut epithelium; other guide letters as in previous figures.

Fig. 6.—Sagittal section of collar epidermis. 1 (anterior) to 5 (posterior), zones of collar epidermis.

Fig. 7.—Dorsal surface of oesophageal region showing arrangement of intestinal pores. gr., genital ridge; ip., intestinal pore; other guide letters as in previous figures.

Fig. 8.—Transverse section of second region of oesophagus. oe., lumen of oesophagus; oo., oocyte; other guide letters as in previous figures.

broad. They are thus intermediate in size between those of *S. cambrensis* (400 μ by 300 μ) and *S. kowalevskii* (375 μ) on the one hand and *S. horsti* (230 μ by 170 μ) and *S. otagoensis* (250 μ) on the other. Some six to ten mature oocytes appear in one transverse section as well as a larger number of immature ones. The latter are usually located medially and dorsally in the ovary, that is in the region of the genital pore, while the mature oocytes occupy a more central or ventral position (Fig. 8).

The oesophagus has the usual three regions. The first of these has an epithelium of moderate thickness which is very much folded and is histologically similar to that of the ventral, non-branchial, part of the pharynx. The second region has a thicker epithelium (Fig. 8) and it is into dorso-lateral grooves in this region that the intestinal pores open. There are six to eight pairs of these, there being no rudimentary pores such as appear in *S. cambrensis*. The third region of the oesophagus has a lower epithelium than the first region and this merges imperceptibly into the hepatic region, which, as in other members of the genus, is indistinguishable externally. The gut in the abdominal region (Fig. 5) has a broad lumen and thin walls. Ventro-laterally the walls are thickened to form two marked parallel ridges, separated by a deep mid-ventral furrow. The ventral musculature in this part of the body is much reduced and there are only very slight traces of the fine bands of dorsal longitudinal muscles which are apparent throughout the branchial and oesophageal regions.

IV. SPECIFIC CHARACTERS AND COMPARISON WITH OTHER SPECIES

The specific characters of *Saccoglossus apantesis* are listed below:

(a) There are between thirty and forty-five pairs of gill clefts.

(b) The gonads start in the mid-branchial region and form marked dorso-lateral ridges.

(c) The oocytes are nearly spherical, measuring about 310 μ by 285 μ.

(d) The ventral, longitudinal muscles of the trunk form distinct ventro-lateral ridges in the posterior branchial and oesophageal regions.

(e) There are six to eight pairs of intestinal pores.

(f) The epidermis of the collar has five distinct zones, the second of these being almost equal in extent to the remaining four added together.

(g) The dorsal proboscis groove is but slightly developed in the posterior quarter of the proboscis.

(h) The longitudinal musculature of the proboscis is arranged in at least nine or ten complete concentric rings.

(i) The stomochord has a ventral diverticulum which is directed slightly backwards and is partially grasped by the bluntly bifid tip of the proboscis skeleton.

(j) The crura of the proboscis skeleton extend about halfway along the length of the collar and embrace slightly more than half the circumference of the buccal cavity.

S. apantesis is the fifteenth member of the genus to be described. It can been distinguished from the other species on the following combinations of characters:

S. sulcatus (Spengel). Loc. Japan. Deep dorsal sulcus on the proboscis giving it a crescentic cross section; ten to eleven pairs of gills.

S. otagoensis (Benham). Loc. New Zealand. Deep dorsal groove on the proboscis; ten to fifteen pairs of gill pores; longitudinal muscles of the proboscis in three or four concentric rings; gonads extend anteriorly to the level of the fourth gill pore; one pair of intestinal pores.

S. pygmaeus (Hinrichs and Jacobi). Loc. Heligoland. Nine to twenty-two pairs of gill pores; longitudinal muscles of proboscis not in concentric rings;

gonads begin at posterior extremity of the branchial region; one pair of intestinal pores; very small form, about three centimetres long.

S. gurneyi (Robinson). Loc. Suez. Collar nearly twice as broad as long; longitudinal muscles of proboscis not in concentric rings; forty to sixty pairs of gill pores; median proboscis pore; gonads begin immediately behind the collar; intestinal pores absent (?).

S. carabaicus (van der Horst). Loc. West Indies. Longitudinal muscles of the proboscis not in concentric rings; median proboscis pore; more than fifty pairs of gill pores; gonads begin between the fourth and fifth gill pores.

S. bournei (Menon). Loc. Madras. Longitudinal muscles of the proboscis not in concentric rings; crura of proboscis skeleton extend to the hinder end of the collar; ventral musculature of the trunk region not especially thick; gonads begin immediately behind the collar.

S. pusillus (Ritter). Loc. California. Crura of the proboscis skeleton extend to the hinder end of the collar and embrace three-quarters of the circumference of the buccal cavity; about sixty pairs of gill pores; one pair of intestinal pores.

S. mereschkowskii (Nic. Wagner). Loc. North-Eastern Russia. Fifty pairs of gill pores; endplate of the proboscis skeleton bears a long dorso-median spine; collar epidermis very thick (0·5 mm.).

S. inhacensis (Kapelus). Loc. South-East Africa. Eighty-two or more pairs of gill pores; longitudinal muscles of the proboscis not in concentric rings; gonads begin at the level of the fourth gill pores; four pairs of intestinal pores, the first of which has four internal openings.

S. kowalevskyi (A. Agassiz). Loc. Atlantic coast of the U.S.A. A hundred pairs of gill pores; genital folds begin one millimetre behind the collar; only four or five rings clearly visible in the longitudinal muscle of the proboscis; four to six pairs of intestinal pores.

S. ruber (Tattersall). Loc. Western Ireland. Longitudinal muscles of the proboscis not in concentric rings; no genital or muscular ridges on the trunk; fifty-six to sixty-four pairs of gill pores.

S. serpentinus (Assheton). Loc. Scotland. Very long proboscis and body; trunk circular in cross section, without genital or muscular ridges, sixty pairs of gill pores; longitudinal muscle of proboscis not in concentric rings.

S. cambrensis (Brambell and Cole). Loc. North Wales. Trunk circular in cross section without genital or muscular ridges; sixty to ninety pairs of gill pores; four to six ill-defined concentric rings in the periferal part of the longitudinal musculature of the proboscis; eight to twelve pairs of intestinal pores, the first three to five pairs being rudimentary. Intestinal pores arranged parallel to the mid-dorsal line.

S. horsti (Brambell and Goodheart). Loc. Southern England. Dorsal and ventral grooves present on the proboscis throughout its length; gonads begin within one millimetre of the collar; one hundred to one hundred and forty pairs of gill pores; four to eight pairs of intestinal pores.

V. REFERENCES

BENHAM, W. B., 1899. *Balanoglossus otagoensis* n.sp., Quart. J. Micr. Sci. 42, 497-504.

BRAMBELL, F. W., ROGERS, and COLE, H. A., 1939a. *Saccoglossus cambrensis* sp. n., an Enteropneust occurring in Wales, Proc. Zool. Soc. London, B, 109, 211-236.

BRAMBELL, F. W., ROGERS, and COLE, H. A., 1939b. The pre-oral Ciliary Organ of the Enteropneusta; its occurrence, structure and possible phylogenetic significance, Proc. Zool. Soc. London, B, 109, 181-193.

BRAMBELL, F. W., ROGER, and GOODHEART, C. B., 1941. *Saccoglossus horsti* sp. n., an Enteropneust occurring in the Solent, J. Mar. Biol. Ass. U.K., 25, 283-301.

DAKIN, W. J., 1916. A new species of Enteropneusta, *Ptychodera pelsarti* from the Abrolhos Islands, Journ. Linn. Soc. London Zool., 33, 85-100.

HILL, J. P., 1891. On a new species of Enteropneusta (*Ptychodera australiensis*) from the coast of New South Wales, Proc. Linn. Soc. N.S.W., 10, 1-42.

HILL, J. P., 1897. The Enteropneusta of Funafuti, Mem. Australian Mus., 3, 205-210 and 335-346.
HORST, C. J. VAN DER, 1927-39. Hemichordata. Bronn's Klassen und Ordnungen des Tier-Reichs, Bd. 4, Abt. 4, Buch 2, Tiel 2.
KAPELUS, F. F., 1936. The anatomy of the Enteropneust, *Saccoglossus inhacensis* sp. n., Ann. Natal Mus. 8, 47-94.
SPENGEL, J. W., 1893. Die Enteropneusten des Golfes von Neapel. Fauna and Flora des Golfes von Neapel, Monogr. 18.
TREWAVAS, E., 1931. Enteropneusta. Great Barrier Reef Exp. 1928 9. Sci. Rep. 4. 2.

THE ADELAIDE EARTHQUAKE OF 1ST MARCH, 1954

BY C. KERR-GRANT

Summary

In the early hours of 1st March, 1954, most of the inhabitants of the city of Adelaide were awakened by a loud rumbling noise followed by a shaking severe enough to crack the walls and loosen plaster from many houses. For most persons in Adelaide, this was their first experience of an earthquake, and it is the first record in almost a hundred years of any movements in the earth's crust in the vicinity of the city. Although a relatively minor one by the standards of countries prone to earthquakes, it was sufficiently severe to cause material damage to many buildings, as the possibility of earthquake damage had never been taken into consideration in their construction. There were no injuries as a result of the earthquake.

THE ADELAIDE EARTHQUAKE OF 1st MARCH, 1954*

By C. Kerr-Grant†

[Read 10 Nov. 1955]

INTRODUCTION

In the early hours of 1st March, 1954, most of the inhabitants of the city of Adelaide were awakened by a loud rumbling noise followed by a shaking severe enough to crack the walls and loosen plaster from many houses. For most persons in Adelaide, this was their first experience of an earthquake, and it is the first record in almost a hundred years of any movements in the earth's crust in the vicinity of the city. Although a relatively minor one by the standards of countries prone to earthquakes, it was sufficiently severe to cause material damage to many buildings, as the possibility of earthquake damage had never been taken into consideration in their construction. There were no injuries as a result of the earthquake.

DATA RECORDED AND COLLECTED

The earthquake occurred at 18 h. 10 m. G.M.T. approximately on 28th February, 1954 (3.40 a.m. local time on 1st March). Only the initial shock was recorded on the Milne-Shaw seismograph operated by the Adelaide University, this instrument being thrown out of action by the first shock of the primary wave. The other instrument at Adelaide, a Milne seismograph registering the N-S component of seismic vibrations, was not operating. The Milne-Shaw instrument normally records the E-W component. The earthquake was also recorded on the seismographs in Melbourne, Sydney, Brisbane and Perth, but not, as far as is known, outside Australia. The epicentre has been established as being on or very close to the Eden fault line, in the vicinity of the suburbs of Darlington and Seacliff. Minor aftershocks were felt two days after the earthquake, and a further tremor occurred in the morning of 3rd September, originating apparently from the same epicentre as the original earthquake.

The main shock of the earthquake was estimated to last from 5 to 20 seconds in the suburban areas of Adelaide, the time being greater in the northern suburbs of the city. Near the epicentre the shock has been described as being very abrupt and was of only two or three seconds duration.

In the absence of any instrumental records from distances under 400 miles from the epicentre, numerous reports available of the effects of the earthquake and the experiences of persons who felt it were investigated by the geophysical staff of the Department of Mines. An abundance of information was naturally available from the Adelaide metropolitan area, but data from more remote country areas is sparse as few people were awake at the time of the earthquake. From these reports it has been possible to draw isoseismal lines and establish the approximate position of the epicentre (Figs. 1 and 2). The maximum intensity of the earthquake has been established as Intensity 8 on the Modified Mercalli scale. A second or minor epicentre with Intensity 7 appears to occur in the vicinity of Beaumont. Considerable disturbance and damage to build-

* Published with the approval of the Director of Mines.

† Department of Mines, South Australia.

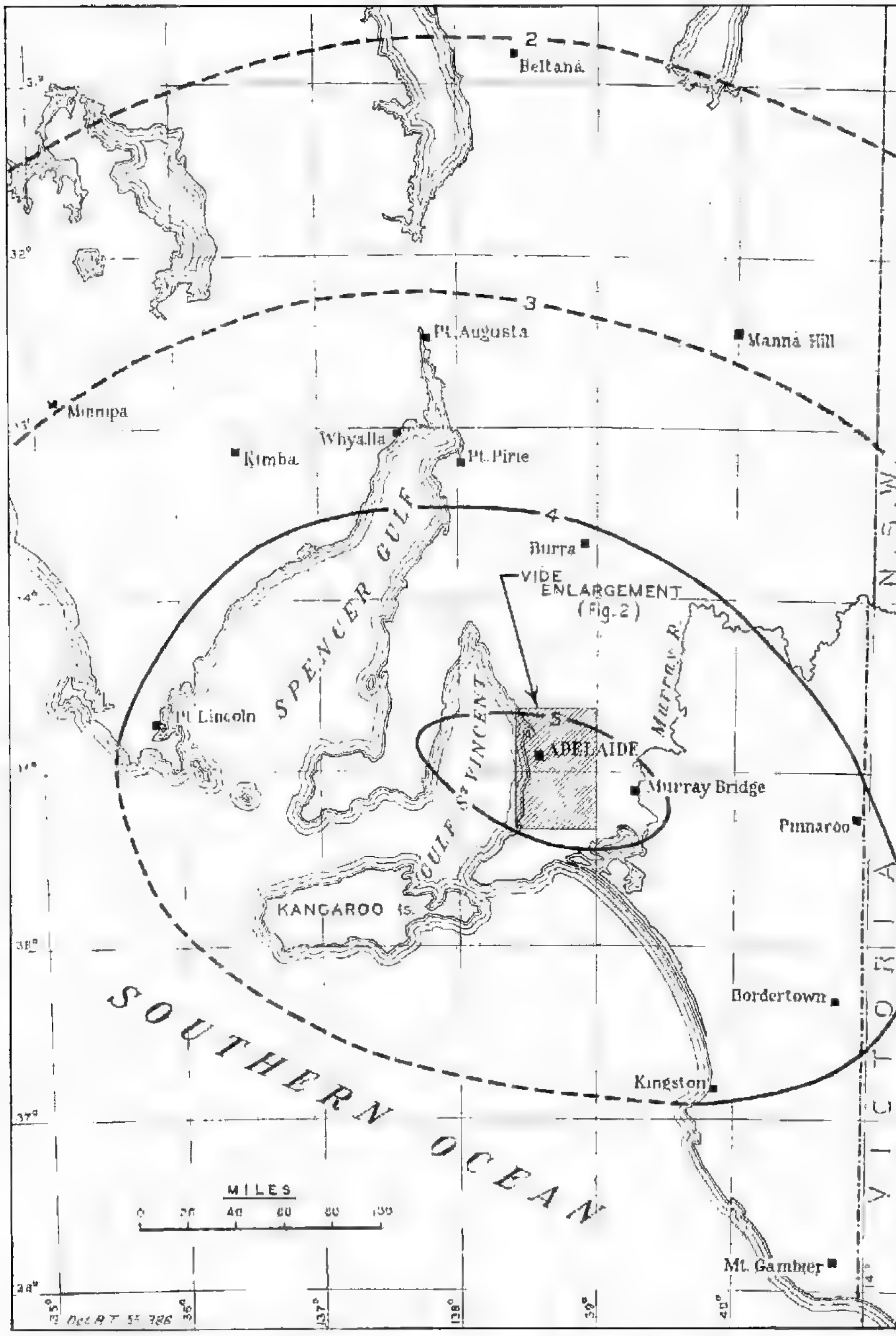


Fig. 1 Isoseismal lines showing earthquake centre near Adelaide, *vide* Fig. 2 for enlargement.

ings occurred also in the suburb of Blackwood, but this can be accounted for by the fact that much of Blackwood is built on subsoil of hillsides, which tended to slip down hill during the disturbance.

The earthquake, unfortunately, did not record in sufficient detail on other seismographs in Australia to identify with certainty any but the main P and S

phases. The times of these phases at Brisbane, Melbourne and Sydney, read by the Riverview Observatory staff; and at Perth, read by the Government Astronomer, are:

	P		S		
Melbourne	18h.11m.20s.	G.M.T.	18h.12m.25s.	G.M.T.	S°—18h.11m.45s.
Sydney	18h.12m.26s.	G.M.T.	18h.14m.38s.	G.M.T.	PP—18h.12m.36s.
Brisbane	18h.13m.11·9s.	G.M.T.	18h.16m.13s.	G.M.T.	PP—18h.12m.21·6s.
Perth	18h.20m.11s.	G.M.T.	18h.22m.23s.	G.M.T.	

The Melbourne records were obtained from a Wood-Anderson seismograph registering the N-S component with magnification 120 times (Fig. 3) and a Milne-Shaw instrument the E-W with magnification 250 times (Fig. 4), Sydney from 3 seismographs giving E-W, N-S and vertical components, and Brisbane using a Benioff short period seismograph for the E-W (?) component, and a Sprengnether N-S seismograph. The Brisbane record indicates in addition subsequent arrivals at 18h. 13m. 14·8s. and 18h. 13m. 16·8s. The earthquake was not recorded in New Zealand.

Numerous independent witnesses who were outdoors or awake at the time of the earthquake reported the occurrence of a light or flash in the sky at the time of the earthquake. No satisfactory explanation of this has been forthcoming. Many of these observers could not indicate the direction whence the light came, as they were indoors and saw the sky or their room lit up, but most of those who were outdoors agreed that it originated in the east, being themselves to the westward of the epicentre. Two reports were received from observers who considered the light to come from the direction opposite to the epicentre. Similar indications of light have been often recorded in connection with other earthquakes. It is quite unlikely that any of the observers would have known of this phenomenon previously, as several of them were milkmen on their rounds. There was no cloud at the time the flash was reported.

The following causes have been suggested as an explanation of this phenomenon:

(1) A bright meteor falling at the instant of the earthquake.

(2) Electric power lines shorting due to the movement caused by the earthquake.

(3) A physiological effect on the eyes caused by the vibrations of the earthquake.

(4) A psychological effect due to fear caused by the earthquake.

(5) An unexplained physical effect caused by the earthquake.

Of these suggestions, the first is exceedingly unlikely as the meteor itself should have been recognised by some observers; the second would have caused an appreciable increase of load at the power station or a breakdown if on a scale large enough to account for all the reports of light seen, and no immediate increase of load was recorded by the State Electricity Trust; the third is considered unlikely by Davison and others as vibrations of the frequency of the earthquake waves normally do not affect people, also it would seem unlikely that observers could see other objects by the flash of this light as several of them report; the latter objection applies in part to the fourth suggestion; no mechanism is known to have been suggested as a means of explaining any physical reason for such a phenomenon. Other suggestions, that the light is the reflection of light from the interior of the earth displayed through fissures occurring at the moment of the earthquake, or to light generated by the faulting movements themselves, seem difficult to take seriously. On the other hand, it is difficult to discount the veracity of all the observers reporting the lights in the sky, and the cause of this presumed effect must remain temporarily unsolved.

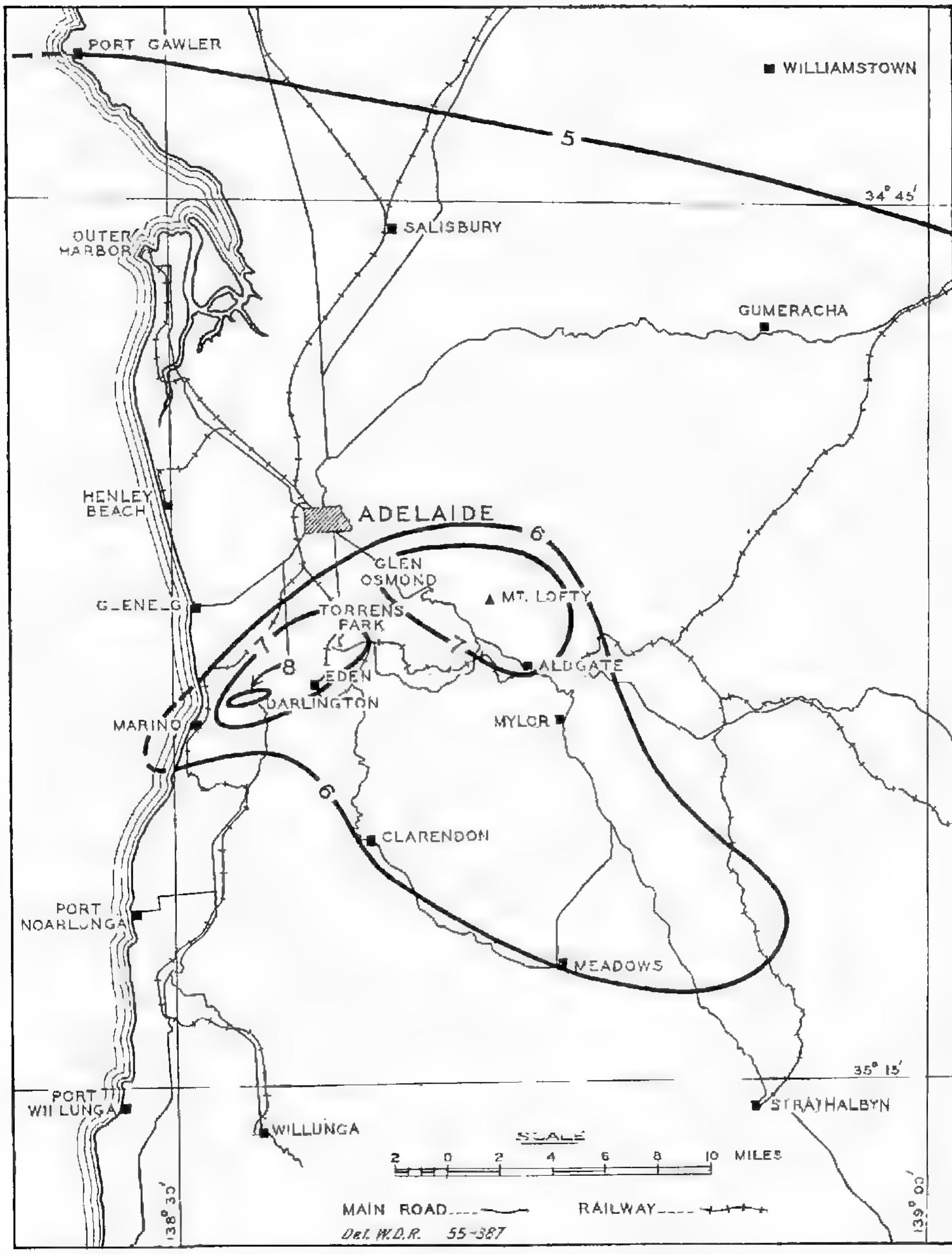


Fig. 2 Enlargement of inset Fig. 1. Isoseismal lines showing main centre of intensity eight and second minor centre of intensity seven.

INTERPRETATION OF THE DATA

The isoseismal lines establish the position of the epicentral region as a strip running between Darlington and Seacliff. The maximum disturbance appeared to be confined to two or three elongated zones less than a hundred yards wide, in the vicinity of the suburbs of Darlington, Seacombe Park and to a lesser

extent Beaumont. These zones lie along a line corresponding almost exactly to the known or inferred trace of the Eden Fault. This fault can be seen near Darlington where it crosses the Shepherds Hill road, on the coast near Marino Rocks, and near Mitcham; between Darlington and Seacliff the scarp has weathered to an alluvial slope, and the actual fault trace is obscured.

The minor epicentre near Beaumont appears to be a genuine region of increased disturbance; it is possible that Beaumont and Darlington represent in a way antinodes of the vibrations transmitted to the surface, or possibly a separate movement under Beaumont was triggered by the main disturbance. There is no evidence that separate movements occurred at appreciably different times.

The time marks on the Adelaide record do not enable the instant of origin to be determined precisely. The time of origin was computed as 18h. 09m. 37s. from the Riverview records by Father Burke-Gaffney.

Unfortunately, the records at Melbourne and Brisbane are too disturbed by microseisms and the intensities recorded were too small to get precise measurements of all the phases. Before the determination of the epicentre by isoseismal lines a preliminary determination made at Riverview indicated an epicentre in the vicinity of Kangaroo Island. From this it would appear that between Adelaide and Sydney the velocity of both P and S waves may be anomalous.

From the shape of the isoseismal lines the depth of the focus of the earthquake is evidently very shallow. Standard methods of determination do not differentiate between depths of focus less than two or three kilometres and the focus is evidently less than this; more precise determination does not seem possible.

PREVIOUS EARTHQUAKES IN SOUTH AUSTRALIA

Only three previous earthquakes originating in South Australia have been recorded in any detail. Although minor tremors are quite frequent, most of the latter can be attributed to subsidence of the subsoil on the slopes of hillsides, and are therefore quite superficial. Minor tremors of this kind have often been noted during observations with a gravity meter in the Adelaide plains, the writer having noted them especially in the suburbs of Millswood and Goodwood.

The earliest reported earthquake in South Australia is by the Rev. Julian Edmund Woods, who mentions a "severe shock" felt in Adelaide in June, 1856[1]; another shock was reported by the same author to have been felt in December, 1861, in what was referred to as the Stone Hut Range, in the vicinity of Lake Bonney.

The known earthquakes of moderate intensity which have occurred in South Australia comprise:

(1) 10th May, 1897, at 2.25 p.m., epicentre near Beachport, intensity IX on Rossi-Forel Scale. Aftershocks were reported for some months.

(2) 19th September, 1902, at 6.35 a.m. and 8.05 p.m., epicentre near Warooka on Yorke Peninsula, intensity 8 on Mercalli scale. A series of aftershocks occurred until 24th September.

(3) 8th April, 1948, epicentre 10 miles N.W. of Beachport, intensity 7(?). No detailed report has apparently been written on this earthquake.

Minor shocks occur almost every year in the Mount Lofty and Flinders Ranges. A summary of the recorded shocks from 1893-1903 is given by Howchin,[3] and from 1904-1908 by Dodwell.[4] Several minor earthquakes of intensities up to 5 or 6 on the modified Mercalli scale have been reported from the Flinders Ranges, Beltana being the seat of their most frequent occurrence. It is unfortunate that the systematic collection of records of minor earthquake shocks does not appear to have been continued since this time.

CAUSES OF THE EARTHQUAKE

In general terms, the earthquake appears to be the result of a slow continuation or readjustment of the movement along the Eden fault which formed the scarp of the Adelaide Hills. It does not seem possible to ascertain from the direct evidence of the earthquake whether this movement comprised a continuation of the original movement with an upthrow to the east, or a reversal due to a settling back. Cracks in the ground which appeared at Darlington and Seacombe Park do not indicate any appreciable movement. They are probably merely due to subsidence of the subsoil downhill. The only inference possible is that any movement on the fault plane must have been quite small—of the order of an inch or two.

A visit was paid to an abandoned quarry near Gilberton Road, Seacombe Park, where very recent displacements in the slate of the quarry were evident. This quarry appears to be south of the inferred position of the Eden fault in this area, and after an examination of the quarry it was concluded that the

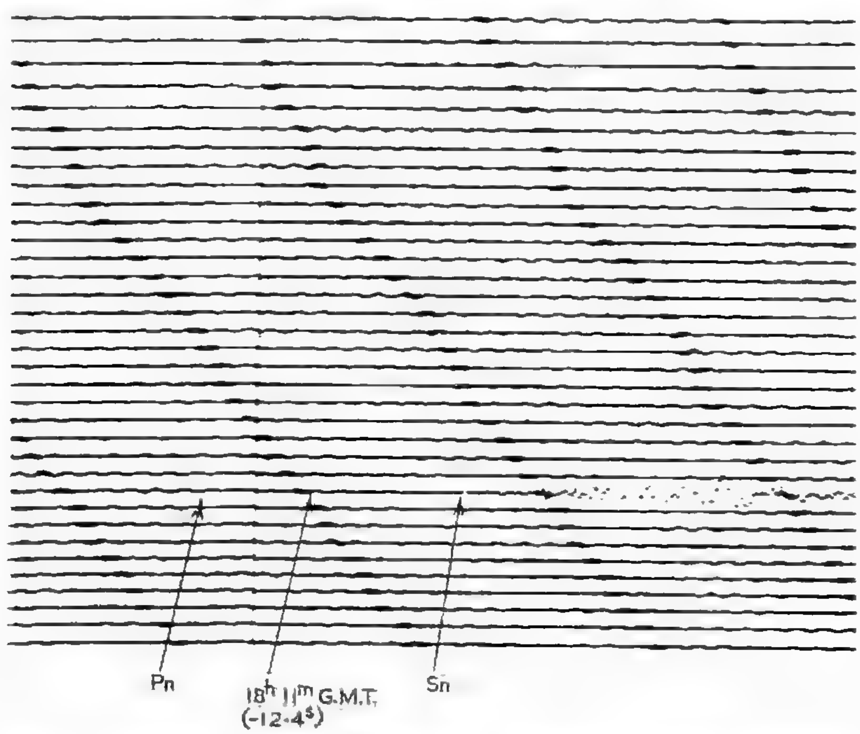


Fig. 3—Wood-Anderson record, Melbourne Observatory, 28th Feb., 1954.

observed movement was merely gravitational displacement of the already fractured rock. The maximum displacement seen was approximately two inches.

Negative isostatic gravity anomalies occur on the Adelaide plains or western side of the Eden fault scarp, compared with slight positive anomalies over the hills area. If the Eden fault is assumed to be a normal fault, it is probable that the earthquake produced a slight relative rising of the plain and sinking of the hills. If, however, as seems more likely from geophysical evidence, the fault is predominantly a thrust fault, and isostatic readjustment is prevented by compressive stresses in the crust, it is impossible to decide whether the motion was due to a continuation of the thrust movement or a readjustment caused by its relief; the former hypothesis seems more plausible, as the movement causing the faulting is comparatively recent geologically having occurred since Pleistocene time, and is possibly still in progress to some extent.

There may be some significance in the fact that the epicentre is in a region where the fault trace bends from a N.N.E-S.S.W direction to nearly east-west since a slow adjustment along an active fault plane might be impeded where the plane is curved, allowing greater shearing stresses to build up before slipping occurred.

The actual triggering mechanism setting off the earthquake cannot be surmised.

The tides at this date were almost neap tides, high tides being at 2.54 a.m. and 5.25 p.m. on 1st March and low water at 10.59 a.m., so that although the weight of water in the gulf due to the high tide prior to the earthquake may have assisted in triggering it at the particular hour at which it occured, some further mechanism must have been responsible for initiating the movement at a period of neap tides rather than at one of spring tides.

Also the barometric gradient at the time of the earthquake was not favourable to triggering the earthquake. At 3 a.m. on 1st March, 1954 (local time), the gradient was less than 1 millibar per hundred miles in a direction from S.S.W. to N.N.E., the centre of the anticyclone being over Kangaroo Island, pressure 1020 millibars, while that at Adelaide was 1017·6 millibars. The major component of this gradient is parallel to and not across the fault.

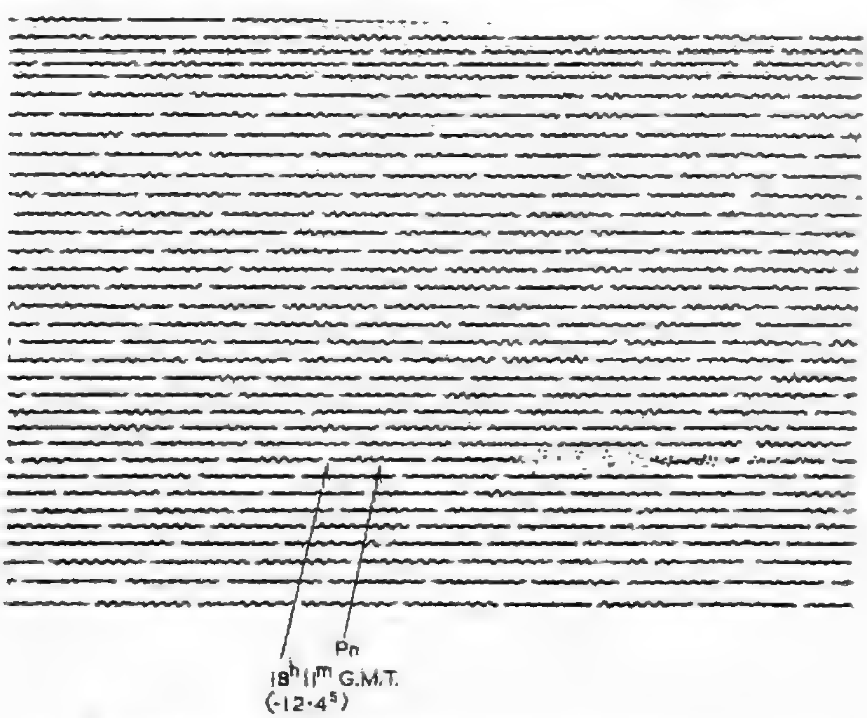


Fig. 4—Milne-Shaw record, Melbourne Observatory, 28th Feb., 1954.

EFFECTS OF THE EARTHQUAKE

The most evident effect produced by the earthquake was the material damage done to large numbers of buildings in the Adelaide suburban area and in a few districts in the Adelaide Hills adjacent to the epicentre. Some houses in the vicinity of Darlington and Seacombe Park were damaged beyond repair, the worst damage observed being a house occupied by Mr. C. E. Tiller, proprietor of the Darlington Sawmills, which was in the course of being partially rebuilt. Two unbraced walls at the rear of the house collapsed and large cracks appeared in the interior and exterior walls of the house, one portion

of an interior wall being displaced two or three inches transversally at the position of the crack. Plate I shows some of the worst examples of damage sustained.

Considerable damage to buildings also occurred in Blackwood, but this has been attributed to subsidence of the sloping ground on which most houses are built rather than to any local increase in the intensity of the seismic vibrations. The amount of damage, as is to be expected, varied considerably with the type of structure. Older houses built without dressed stone and with lime instead of cement mortar are particularly prone to damage. The most unsuitable type of building appears to be a stone veneer or facing over brick or cement walls. By a singular coincidence, a large new housing area near Darlington has been built mainly with wooden houses, one of the few areas of this type in South Australia. Only minor damage to the brickwork chimneys was reported from this area.

Estimates of the total amount being expended by insurance companies in earthquake repairs exceed four million pounds. This figure is misleadingly large for an earthquake of this intensity for three reasons:

(1) The almost universal use of brick or stone for building construction in Adelaide.

(2) The pre-existence of numerous minor cracks in masonry structures often caused by other factors, which the earthquake opened up sufficiently to necessitate repair.

(3) The absence of previous earthquakes resulting in the existence of numerous buildings unable to withstand even relatively minor seismic disturbances without some damage.

Another curious feature of the earthquake was the rotation of three chimneys on top of the E.S. and A. Bank in King William Street, Adelaide. N. B. Tindale has also reported that many objects in the South Australian Museum rotated in an anticlockwise direction by about 10-15 degrees. The movement near Waite Agricultural Research Institute was in a N.-S. direction from the evidence obtained from books on shelves of Waite Institute Library.

In addition to the structural damage caused by the earthquake, numerous new springs in parts of the hills and metropolitan area were reported and an increased or renewed flow occurred in existing springs. Reports of new springs were received from:

The National Park, Belair;
Mylor, and on the Meadows-Willunga Road;
Woodside;
Crafers, Brown Hill Creek and Mt. Barker Creek.

A bore at Golden Grove, and another at Biggs Flat in the Hundred of Kuitpo, were reported to have stopped flowing.

Some time after the earthquake, in April after half an inch of rain had fallen in the previous night, a mud flow was reported on the property of Mr. and Mrs. Fendler in the vicinity of the upper parts of the Brown Hill Creek near the Mount Barker Road. A river of mud resembling a lava flow started near the head of a steep tributary on the south side of the Brown Hill Creek, and flowed for about half a mile across the main valley through the middle of a field covered with potatoes. The mud was about three feet deep and carried small bushes and other objects along on the top of it. This movement was quite slow and took about a day to reach its maximum extent, ceasing a few yards before reaching the creek which flows on the north-west side of the valley.

Although this phenomenon cannot be directly related to the earthquake, it is considered that it was caused by the loosening of the soil on the hillsides

above, which the advent of the winter rains made sufficiently plastic to flow as viscous mud.

Apart from the physical effects of this earthquake, the realisation of the enormous structural damage to buildings which can be caused by even a moderate earthquake greatly stimulated local interest in earthquakes in all sections of the community. Many enquiries have been received as to the likelihood and probable frequency of future earthquakes in the Adelaide plains area. This, of course, cannot be predicted particularly since insufficient seismic stations are available to determine the overall seismicity of the State.

ACKNOWLEDGMENTS

The writer is indebted to the Director of Riverview College Observatory, N.S.W., for data recorded at Riverview College and valuable comments and information on the records obtained at Sydney, Melbourne and Brisbane, and to the Chief Geophysicist of the Bureau of Mineral Resources, Geology and Geophysics, Melbourne, for the records obtained in Melbourne, to the Professor of Geology at the University of Queensland for photographic copies of the records obtained at Brisbane, to the Government Astronomer of Western Australia for information on the arrival times of the disturbance, and to the Director of the Seismological Observatory of Wellington, New Zealand, for a report on the absence of recordings in New Zealand; also to the Australian Broadcasting Commission and the representatives of the press in Adelaide for passing on information collected by their news services. The co-operation of many persons too numerous to name individually who communicated their observations and experiences enabled the construction of an isoseismal map.

Assistance in preparation of the data was given by Assistant Geophysicist D. M. Pegum of the Geological Survey of South Australia and the permission of the Director of Mines to publish this report is acknowledged.

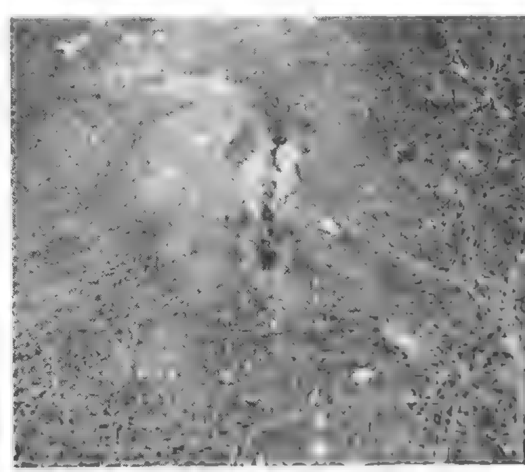
REFERENCES

1 Woods, Rev. Julian Edmund, Geological Observations in South Australia, London, 1862 (p. 213).
2 Howchin, Walter, The Geology of South Australia, 1st Edition, Adelaide, 1918, pp. 267-270.
3 Howchin, Walter, The Geography of South Australia. Christchurch, New Zealand. 1910, pp. 135-141.
4 Dodwell, G. F., Proc. Aust. Assoc. Adv. Science, Vol. xii, 1909, pp. 416-423.

Stone veneer house in Aboyne Ave., Seacombe Park, showing damaged front.

House in Seacombe Road made of cement blocks and stone veneer.

Damage to Mr. C. E. Tiller's house, Darlington.



Fissure in front path 100 yards S.W. of Mr. Tiller's house.

ABSTRACT OF EXHIBITS AND LECTURES AT MEETINGS OF THE SOCIETY DURING 1955

Summary

ABSTRACT OF EXHIBITS AND LECTURES AT MEETINGS OF THE SOCIETY DURING 1955

May 12—P. F. Lawson (South Australian Museum): Illustrated talk on the 1953 Expedition to Lake Callabonna for the purpose of collecting fossil remains of mammals.

April 14—I. M. Thomas: Illustrated talk on his recent visits to marine biological stations in Great Britain and Western Europe.

June 9—D. King introduced a discussion on the geology of the Lake Eyre region.
C. W. Bonython: Illustrated talk entitled "Lake Eyre," in which he exhibited colour transparencies and a cinema film in colour.
I. M. Thomas exhibited and explained new equipment for plankton sampling in coastal waters.

July 14—R. L. Specht: Illustrated talk, "Some problems of plant nutrition and soil-water relationships associated with the Ninety-Mile Plains of South Australia."
F. J. Hilton showed pictures illustrating differences of vegetation in parts of the Flinders Ranges before and after rain.

August 11—T. R. N. Lothian: Illustrated talk, "Cultivating dry-land plants."

Sept. 8—K. H. Northcote: Soil studies in the Barossa district.

Nov. 10—C. P. Mountford showed a cinema film in colour entitled "Island of Yoi."

BALANCE SHEET

Summary

ROYAL SOCIETY OF SOUTH AUSTRALIA (INCORPORATED)

Receipts and Payments for Year ended 30th September, 1955.

RECEIPTS

	£	s.	d.	£	s.	d.
To Balance 1/10/54 ...				554	18	10
,, Subscriptions				351	18	5
,, Government Grant for printing, etc.:						
1954-5 (balance)	1,125	0	0			
1955-6 (1st instlt.)	375	0	0			
				1,500	0	0
,, Sale of Publications and Reprints				301	9	3
,, Interest				232	18	11
,, Hire of Hall ...				3	9	0
,, Ferrier Bequest for Field Naturalists...				1,262	4	3
				£4,206	18	8

PAYMENTS

				£	s.	d.	£	s.	d.
By Printing and Publishing Reprints ..							86	17	6
,, Library Assistants ..							185	12	6
,, Printing and Stationery							56	15	3
,, Postages, Duty Stamps, etc.							50	10	3
,, Postages on Transactions							56	3	8
,, Cases and Packing Books, etc. ...							137	12	6
,, "Verco" Medallions .							15	8	3
,, Cleaning							47	12	0
,, Insurance ..							7	1	7
,, Lighting							16	18	6
,, Alterations to Lighting							106	5	0
,, Sundries							5	16	1
,, Field Naturalists' Section (bequest) ...							1,262	4	3
,, Balance—									
Savings Bank of S.A.—									
Gen'l A/c.	562	9	5						
Ex-Endow. Fund	15	2	9						
Rundle St. A/c ...	1,679	4	6						
	2,256	16	8						
Less Outstanding Cheques									
6 5 0									
75 19 10									
2 0									
1 18 0									
4 15 0	88	19	10						
				2,167	16	10			
,, Cash on Hand .				4	4	6			
							2,172	1	4
							£4,206	18	8

ENDOWMENT FUND

Receipts and Payments for Year ended 30th September, 1955.

	£	s.	d.	£	s.	d.
1954—Oct. 1:						
To Balance—						
Commonw'th Inscribed Stock	6,010	0	0			
Savings Bank of S.A.	62	18	7			
				6,072	18	7
1955—Sept. 30:						
Interest—						
Inscribed Stock ...	199	11	6			
Savings Bank of S.A. ..	33	7	5			
				232	18	11
				£6,305	17	6

	£	s.	d.	£	s.	d.
1955—Sept. 30:						
By Revenue A/c. . .				232	18	11
,, Balance—						
Common'wth Inscribed Stock	6,010	0	0			
Savings Bank of S.A.	62	18	7			
				6,072	18	7
				£6,305	17	6

Audited and found correct. The Stock and Bank Balances have been verified by certificates from the respective institutions.

F. M. ANGEL } Hon.
N. S. ANGEL, A.U.A. Com. } Auditors

H. M. HALE, Hon. Treasurer.

Adelaide, 11th October, 1955.

AWARDS OF THE SIR JOSEPH VERCO MEDAL AND LIST OF FELLOW, MEMBERS, ETC.

Summary

AWARDS OF THE SIR JOSEPH VERCO MEDAL

1929 Prof. Walter Howchin, F.C.S.
1930 John McC. Black, A.L.S.
1931 Prof. Sir Douglas Mawson, O.B.E., D.Sc., B.E., F.R.S.
1933 Prof. J. Burton Cleland, M.D.
1935 Prof. T. Harvey Johnston, M.A., D.Sc.
1938 Prof. J. A. Prescott, D.Sc., F.A.I.C.
1943 Herbert Womersley, A.L.S., F.R.E.S.
1944 Prof. J. G. Wood, D.Sc., Ph.D.
1945 Cecil T. Madigan, M.A., B.E., D.Sc., F.G.S.
1946 Herbert M. Hale, O.B.E.
1955 L. Keith Ward, I.S.O., B.A., B.E., D.Sc.

LIST OF FELLOWS, MEMBERS, ETC.

AS AT 30th SEPTEMBER, 1955.

Those marked with an asterisk (*) have contributed papers published in the Society's Transactions. Those marked with a dagger (†) are Life Members.

Any change in address or any other changes should be notified to the Secretary.

Note—The publications of the Society are not sent to those members whose subscriptions are in arrear.

Honorary Fellows

Date of Election

1949. *Cleland, Prof. J. B., M.D., Dashwood Road, Beaumont, S.A.—*Fellow*, 1895-1949; *Verco Medal*, 1933; *Council*, 1921-26, 1932-37; *President*, 1927-28, 1940-41; *Vice-President*, 1926-27, 1941-42.

1955. *Mawson, Prof. Sir Douglas, O.B.E., D.Sc., B.E., F.R.S., University of Adelaide—*Verco Medal*, 1931; *President*, 1924-25, 1944-45; *Vice-President*, 1923-24, 1925-26; *Council*, 1941-43.

1955. *Osborn, Prof. T. G. B., D.Sc., 22 Hardwicke Street, Balwyn, Victoria—*Council*, 1915-20, 1922-24; *President*, 1925-26; *Vice-President*, 1924-25, 1926-27.

1955. *Ward, L. K., I.S.O., B.A., B.E., D.Sc., 22 Northumberland Street, Heathpool, Marryatville, S.A. *Council*, 1924-27, 1933-35; *Vice-President*, 1927-28, *President*, 1928-30.

Fellows

1946. Abbie, Prof. A. A., M.D., D.Sc., Ph.D., University of Adelaide.
1953. Adcock, Miss A., 4 Gertrude Street, Norwood, S.A.
1951. Aitchison, G. D., B.E., Civil Engineering Department, University of Melbourne, Carlton, Victoria.
1927. *Alderman, Prof. A. R., Ph.D., D.Sc., F.G.S., University of Adelaide—*Council*, 1937-42, 1954-55, 1955-56.
1951. Anderson, Mrs. S. H., B.Sc., Zoology Dept., University of Adelaide, S.A.
1951. Andrews, J., M.B., B.S., 40 Seafield Avenue, Kingswood, S.A.
1935. *Andrewartha, H. G., M.Agr.Sc., D.Sc., Waite Institute—*Council*, 1949-50; *Vice-President*, 1950-51, 1952-53; *President*, 1951-52.
1935. *Andrewartha, Mrs. H. V., B.Agr.Sc., M.Sc. (nee H. V. Steele), 29 Claremont Avenue, Netherby, S.A.
1929. *Angel, F. M., 34 Fullarton Road, Parkside, S.A.
1939. *Angel, Miss L. M., M.Sc., c/o Mrs. C. Angel, 2 Moore Street, Toorak, Adelaide, S.A.
1945. *Bartlett, H. K., L.Th., 2 Abbotshall Road, Lower Mitcham, S.A.
1950. Beasley, A. K., Harris Street, Marden, S.A.
1950. Beck, R. G., B.Ag.Sc., R.D.A., Lynewood Park, Mil-Lel, via Mount Gambier, S.A.
1932. Begg, P. R., D.D.Sc., L.D.S., Shell House, 170 North Terrace, Adelaide.
1928. Best, R. J., D.Sc., F.A.C.I., Waite Institute (Private Mail Bag), Adelaide.
1934. Black, E. C., M.B., B.S., Magill Road, Tranmere, Adelaide.
1950. Bonnin, N. J., M.B., B.S., F.R.C.S. (Eng.), F.R.A.C.S., 40 Barnard Street, North Adelaide, S.A.
1945. †*Bonython, C. W., B.Sc., A.A.C.I., Romalo House, Romalo Avenue, Magill, S.A.
1940. Bonython, Sir J. Lavington, 263 East Terrace, Adelaide.
1945. *Boomsma, C. D., M.Sc., B.Sc.For., 6 Celtic Avenue, South Road Park, S.A.
1947. *Bowes, D. R., Ph.D., M.Sc., D.I.C., F.G.S., Geology Department, University College, Swansea, Wales.
1939. Brookman, Mrs. R. D. (nee A. Harvey), B.A., Meadows, S.A.

Date of
Election

1944. *BURBIDGE, MISS N. T., M.Sc., C.S.I.R.O., Div. Plant Industry, P.O. Box 109, Canberra, A.C.T.
1925. BURDON, R. S., D.Sc., University of Adelaide—*Council*, 1946-47, 1947-48, 1948-49.
1922. *CAMPBELL, PROF. T. D., D.D.Sc., D.Sc., Dental Dept., Adelaide Hospital, Adelaide—*Council*, 1928-32, 1935, 1942-45; *Vice-President*, 1932-34; *President*, 1934-35.
1953. CARTER, A. N., B.Sc., 70 Madeline Street, Burwood, E.13, Victoria.
1929. CHRISTIE, W., M.B., B.S., 7 Walter Street, Hyde Park, Adelaide, S.A.—*Treasurer*, 1933-38.
1955. CLOTHIER, E. A., c/o Department of Mines, Adelaide, S.A.
1949. COLLIVER, F. S., Geology Department, University of Queensland.
1907. *COOKE, W. T., D.Sc., A.A.C.I., 4 South Terrace, Kensington Gardens, S.A.—*Council*, 1938-41; *Vice-President*, 1941-42, 1943-44; *President*, 1942-43.
1929. *COTTON, B. C., S.A. Museum, Adelaide—*Council*, 1943-46, 1948-49; *Vice-President*, 1949-50, 1951; *President*, 1950-51.
1953. DANE, D. M. S., M.B., B.Chir., M.R.C.S., L.R.C.P., B.A., Institute of Medical and Veterinary Science, Frome Road, Adelaide.
1951. DAVIDSON, A. C. L., Ph.D., B.Sc., c/o Burns Philp Trust Co., 7 Bridge Street, Sydney, N.S.W.
1950. DELAND, C. M., M.B., B.S., D.P.H., D.T.M., 29 Gilbert Street, Goodwood, S.A.—*Council*, 1949-51, 1954-56; *Vice-President*, 1951-52, 1953-54; *President*, 1952-53.
1941. DICKINSON, S. B., M.Sc., c/o Department of Mines, 31 Flinders Street, S.A.—*Council*, 1949-51, 1954-56; *Vice-President*, 1951-52, 1953-54; *President*, 1952-53.
1930. DIX, E. V., Hospitals Department, Rundle Street, Adelaide, S.A.
1944. DUNSTONE, S. M. L., M.B., B.S., 170 Payneham Road, St. Peters, Adelaide.
1931. DWYER, J. M., M.B., B.S., 105 Port Road, Hindmarsh, S.A.
1933. *EARDLEY, MISS C. M., M.Sc., University of Adelaide—*Council*, 1943-46.
1945. *EDMONDS, S. J., B.A., M.Sc., Zoology Department, University of Adelaide—*Council*, 1951-55; *Programme Secretary*, 1955-56.
1902. *EDQUIST, A. G., 19 Farrell Street, Glenelg, S.A.—*Council*, 1949-1953.
1927. *FINLAYSON, H. H., 305 Ward Street, North Adelaide—*Council*, 1937-40.
1951. FISHER, R. H., 265 Goodwood Road, Kings Park, S.A.
1923. *FRY, H. K., D.S.O., M.D., B.S., B.Sc., F.R.A.C.P., Town Hall, Adelaide—*Council*, 1933-37; *Vice-President*, 1937-38, 1939-40; *President*, 1938-39.
1951. FULTON, COL. D., C.M.G., C.B.E., Aldgate, S.A.
1955. GILES, E. T. (Dr.), Ph.D., M.Sc., D.I.C., S.A. Museum, North Terrace, Adelaide.
1954. GIBSON, A. A., A.W.A.S.M., Geologist, Mines Department, Adelaide.
1953. *GLAESSNER, M. F., D.Sc., c/o Geology Department, University of Adelaide—*Council*, 1952-54.
1927. GODFREY, F. K., Box 951 H, G.P.O., Adelaide.
1935. †GOLDSACK, H., Coromandel Valley, S.A.
1910. *GRANT, PROF. SIR KERR, M.Sc., F.I.P., 56 Fourth Avenue, St. Peters, S.A.
1951. GREEN, J. W., 6 Bedford Avenue, Subiaco, West Australia.
1904. GRIFFITH, H. D., 13 Dunrobin Road, Brighton, S.A.
1948. GROSS, G. F., B.Sc., South Australian Museum, Adelaide—*Secretary*, 1950-53.
1944. GUPPY, D. J., B.Sc., c/o W.A. Petroleum Co., 251 Adelaide Terrace, Perth, W.A.
1922. *HALE, H. M., O.B.E., c/o S.A. Museum—*Verco Medal*, 1946; *Council*, 1931-34, 1950-53; *Vice-President*, 1934-36, 1937-38; *President*, 1936-37; *Treasurer*, 1938-50, 1953-56.
1949. HALL, D. R., Tea Tree Gully, S.A.
1930. †HANCOCK, N. L., 3 Bewdley, 66 Beresford Road, Rose Bay, N.S.W.
1953. *HANSEN, I. V., B.A., 34 Herbert Road, West Croydon, S.A.
1946. *HARDY, MRS. J. E. (nee A. C. Beckwith), M.Sc., Box 62, Smithton, Tas.
1944. HARRIS, J. R., B.Sc., c/o Waite Institute (Private Mail Bag), Adelaide.
1944. HERRIOT, R. I., B.Agr.Sc., 49 Halsbury Avenue, Kingswood, S.A.
1954. HILTON, F. M., B.Agr.Sc., 298 Magill Road, Beulah Park.
1951. HOCKING, L. J., School House, Renmark West, S.A.
1924. *HOSSFELD, P. S., Ph.D., 132 Fisher Street, Fullarton, S.A.
1944. HUMBLE, D. S. W., M.P.S., J.P., 238 Payneham Road, Payneham, S.A.
1947. HUTTON, J. T., B.Sc., 18 Emily Avenue, Clapham.
1928. IFOULD, P., 14 Wyatt Road, Burnside, S.A.
1945. *JESSUP, R. W., M.Sc., c/o C.S.I.R.O., Canberra, A.C.T.
1950. *JOHNS, R. K., B.Sc., Department of Mines, Flinders Street, Adelaide, S.A.
1954. KEATS, A. L., B.E., c/o North Broken Hill Ltd., Broken Hill.
1939. †KHAKHAR, H. M., Ph.D., M.B., F.R.C.S., Khakhar Buildings, C.P. Tank Road, Bombay, India.
1949. *KING, D., M.Sc., c/o Department of Mines, Flinders Street, Adelaide.
1933. *KLEEMAN, A. W., Ph.D., University of Adelaide—*Secretary*, 1945-48; *Vice-President*, 1948-49, 1950-51; *President*, 1949-50.

Date of Election

1922. Lendon, G. A., M.D., B.S., F.R.C.P., A.M.P. Building, King William Street, Adelaide.

1948. Lothian, T. R. N., N.D.H. (N.Z.), Director, Botanic Gardens, Adelaide—*Treasurer*, 1952-53; *Council*, 1953-56.

1931. *Ludbrook, Mrs. N. H., M.A., Ph.D., D.I.C., F.G.S., Department of Mines, 31 Flinders Street, Adelaide.

1938. Madders, C. B., B.D.S., D.D.S., Shell House, North Terrace, Adelaide.

1953. Maelzer, D. A., B.Sc. (Hons.), Waite Institute, Adelaide.

1939. Marshall, T. J., M.Agr.Sc., Ph.D., Waite Institute (Private Mail Bag), Adelaide—*Council*, 1948-52.

1920. Mayo, Sir Herbert, LL.B., Q.C., 19 Marlborough Street, College Park, S.A.

1950. Mayo, G. M. E., B.Ag.Sc., 29 Marlborough Street, College Park, S.A.

1943. McCarthy, Miss D. F., B.A., B.Sc., 70 Halton Terrace, Kensington Park.

1953. McCartney, J. E., M.D., D.Sc. (Edin.), Institute of Medical and Veterinary Science, Frome Road, Adelaide.

1948. McCulloch, R. N., M.B.E., B.Sc., B.Agr.Sc., Roseworthy Agricultural College, Roseworthy, S.A.

1945. †*Miles, K. R., D.Sc., F.G.S., 11 Church Road, Mitcham, S.A.

1951. Miles, J. A. R., M.A., B.Chir. (Cant.), University of Otago, N.Z.

1952. Milne, K. L., F.C.A., 14 Burlington Street, Walkerville, S.A.

1939. Mincham, V. H., 7 Lewthwaite Street, Whyalla West, S.A.

1925. †Mitchell, Prof. Sir W., K.C.M.G., M.A., D.Sc., Fitzroy Terrace, Prospect, S.A.

1933. Mitchell, Prof. M. L., M.Sc., c/o Elder's Trustee and Executor Co. Ltd., 37 Currie Street, Adelaide.

1951. Mitchell, F. J., c/o The South Australian Museum, North Terrace, Adelaide.

1938. Moorhouse, F. W., M.Sc., Chief Inspector of Fisheries, Simpson Buildings, Gawler Place, Adelaide.

1936. *Mountford, C. P., 25 First Avenue, St. Peters, Adelaide.

1944. Murrell, J. W., Engineering and Water Supply Dept., Victoria Square, Adelaide.

1944. Ninnes, A. R., B.A., R.D.A., 62 Sheffield Street, Malvern, S.A.

1952. Nourse, H. V. V., c/o Union Bank of Australia, Adelaide.

1945. *Northcote, K. H., B.Agr.Sc., A.I.A.S., Waite Institute (Private Mail Bag), Adelaide.

1930. Ockenden, G. P., B.A., School House, Box 63, Kimba, S.A.

1937. *Parkin, L. W., M.Sc., A.S.T.C., c/o Mines Dept., Adelaide—*Secretary*, 1953-56.

1940. Parkinson, K. J., B.Sc., Whitwarta Road, Balaklava, S.A.

1929. Paull, A. G., M.A., B.Sc., 10 Milton Avenue, Fullarton Estate, S.A.

1926. *Piper, C. S., D.Sc., Waite Institute (Private Mail Bag), Adelaide—*Council*, 1941-43; *Vice-President*, 1943-45, 1946-47; *President*, 1945-46.

1948. Powrie, J. K., B.Sc., C.S.I.R.O., Keith, S.A.

1949. Pratt, R. G., 81 Park Terrace, North Unley, S.A.

1925. *Prescott, Prof. J. A., C.B.E., D.Sc., A.I.C., F.R.S., 82 Cross Road, Myrtle Bank, S.A.—*Verco Medal*, 1938; *Council*, 1927-30, 1935-39; *Vice-President*, 1930-32; *President*, 1932-33; *Editor*, 1955-56.

1945. *Pryor, L. D., M.Sc., Dip.For., 32 La Perouse Street, Griffith, Canberra, A.C.T.

1950. *Rattigan, J. H., M.Sc., West Australian Petroleum Co., Perth, W.A.

1951. Rayson, P., B.Sc., c/o Botany Department, University of Adelaide.

1944. Rickman, D. S., M.Sc., B.Agr.Sc., C.S.I.R.O., Division of Nutrition, Adelaide.

1947. Riedel, W. R., B.Sc., c/o Scripps Institution of Oceanography, Dept. of Palaeontology, La Jolla, California, U.S.A.

1947. Rix, C. E., 42 Waymouth Avenue, Glandore, S.A.

1953. Rogers, Prof. S. W. P., Ph.D., Zoology Department, University of Adelaide.

1951. Rowe, S. A., 22 Shelley Street, Firle, S.A.

1951. Rowe, S. E., B.Sc., Gordon Institute of Technology, Geelong, Victoria.

1950. Rudd, Prof. E. A., B.Sc., A.M., University of Adelaide, S.A.

1951. Russell, L. D., c/o High School, Port Pirie, S.A.

1945. Rymill, J. R., Old Penola Estate, Penola, S.A.

1933. Schneider, M., M.B., B.S., 175 North Terrace, Adelaide.

1951. Scott, T. D., B.Sc., c/o S.A. Museum, North Terrace, Adelaide, S.A.—*Programme Secretary*, 1953-55.

1924. *Segnit, R. W., M.A., B.Sc., Engineering and Water Supply Department, Victoria Square, Adelaide—*Secretary*, 1930-35; *Council*, 1937-38; *Vice-President*, 1938-39, 1940-41; *President*, 1939-40.

1925. *Sheard, H., Port Elliot, S.A.

1936. *Sheard, Dr. K., M.Sc., Fisheries Research Div., C.S.I.R.O., University of W.A., Nedlands, W.A.

1951. Shepherd, R. G., B.Sc., c/o Department of Mines, Adelaide.

1934. Shinkfield, R. C., 57 Canterbury Avenue, Trinity Gardens, S.A.

1949. Simpson, D. A., M.B., B.S., The Manor House, Great Haseley, Oxfordshire, England.

1925. †Smith, T. E. Barr, B.A., 25 Currie Street, Adelaide.

Date of
Election

1941. *SMITH, T. L., B.Sc., National University, School of Pacific Studies, Box 4, G.P.O., Canberra, A.C.T.

1941. *SOUTHCOTT, R. V., M.B., B.S., D.T.M. & H., 13 Jasper Street, Hyde Park, S.A.—*Council*, 1949-51, 1952-53; *Treasurer*, 1951-52; *Vice-President*, 1953-54, 1955-56; *President*, 1954-55.

1936. SOUTHWOOD, A. R., M.D., M.S. (Adel.), M.R.C.P., 170 North Terrace, Adelaide.

1947. *SPECHT, R. L., Ph.D., Botany Department, University of Adelaide—*Council*, 1951-.

1930. †*SPRIGG, R. C., M.Sc., 5 Baker Street, Somerton Park.

1951. STEADMAN, REV. W. R., 8 Blairgowrie Road, St. Georges, S.A.

1947. SPURLING, M. B., B.Ag.Sc., Horticultural Branch, Department of Agriculture, Box 901E, G.P.O., Adelaide.

1949. *SPRY, A. H., M.Sc., Geology Department, University of Tasmania.

1938. *STEPHENS, C. G., D.Sc., Waite Institute (Private Mail Bag), Adelaide—*Council*, 1952-54; *Vice-President*, 1954-55; *President*, 1955-56.

1955. SWAINE, C. D., M.B., B.S., Repatriation Sanatorium, Belair, S.A.

1932. SWAN, D. C., M.Sc., Waite Institute (Private Mail Bag), Adelaide—*Secretary*, 1940-42; *Vice-President*, 1946-47, 1948-49; *President*, 1947-48; *Council*, 1953-56.

1948. SWANN, F. J. W., Box 156, P.O., Burnie, Tasmania.

1951. SWIBSKI, P., M.Ag.Sc., 618 Seaview Road, Grange, S.A.

1934. SYMONS, I. G., 35 Murray Street, Lower Mitcham, S.A.—*Editor*, 1947-55; *Council*, 1955-56.

1929. *TAYLOR, J. K., B.A., M.Sc., Waite Institute (Private Mail Bag), Adelaide—*Council*, 1940-43, 1947-50; *Librarian*, 1951-52; *Vice-President*, 1952-53, 1954-55; *President*, 1953-54; *Council*, 1955.

1955. THATCHER, D., B.Sc., Department of Mines, Adelaide.

1948. *THOMAS, I. M., M.Sc. (Wales), University of Adelaide—*Secretary*, 1948-50; *Council*, 1950-53.

1938. *THOMAS, MRS. I. M. (nee P. M. Mawson), M.Sc., 36 King Street, Brighton.

1940. *THOMPSON, CAPT. J. M., 135 Military Road, Semaphore South, S.A.

1923. *TINDALE, N. B., B.Sc., South Australian Museum, Adelaide—*Secretary*, 1935-36; *Council*, 1946-47; *Vice-President*, 1947-48, 1949-50; *President*, 1948-49; *Librarian*, 1952-56.

1955. TUCKER, B. M., B.Sc., 86 Baker Street, Glengowrie.

1925. TURNER, D. C., Brookman Buildings, Grenfell Street, Adelaide.

1950. VEITCH, J. T., Box 92, Port Lincoln, S.A.

1953. WATERMAN, R. A., B.A., M.A., Ph.D., North-western University, Evanston, Illinois, U.S.A.

1954. WEBB, B. P., M.Sc., Radium Hill, S.A.

1954. WELLS, C. B., B.Ag.Sc., Broadlees, Waverley Ridge, Crafers, S.A.

1954. *WHITE, A. R., B.Sc., c/o Geology Depart., King's College, Strand, W.C.2, London.

1946. *WHITTLE, A. W. G., M.Sc., Mines Department, Flinders Street, Adelaide.

1950. WILLIAMS, L. E., "Dunosa," Meningie, S.A.

1946. *WILSON, A. F., M.Sc., University of W.A., Nedlands, W.A.

1933. *WOMERSLEY, H., F.R.E.S., A.L.S. (Hon. causa), S.A. Museum, Adelaide—*Verco Medal*, 1943; *Secretary*, 1936-37; *Editor*, 1937-43, 1945-47; *President*, 1943-44; *Vice-President*, 1944-45; *Rep. Fauna and Flora Protection Committee*, 1945; *Treasurer*, 1950-51.

1954. *WOMERSLEY, H. B. S., Ph.D., University of Adelaide.

1944. WOMERSLEY, J. S., B.Sc., Lae, New Guinea.

1923. *WOOD, PROF. J. G., D.Sc., Ph.D., University of Adelaide—*Verco Medal*, 1944; *Council*, 1938-40; *Vice-President*, 1940-41, 1942-43; *Rep. Fauna and Flora Board*, 1940-; *President*, 1941-42; *Council*, 1944-48.

1950. *WOODARD, G. D., B.Sc., 1 Brigalow Avenue, Kensington Gardens, S.A.

1953. WOODHOUSE, L. R., 15 Robert Street, North Unley, S.A.

1943. WOODLANDS, H., F.R.H.S., Box 989H, G.P.O., Adelaide.

1945. WORTHLEY, B. W., B.A., M.Sc., A.Inst.P., University of Adelaide.

1944. ZIMMER, W. J., Dip.For., F.L.S. (Lon.), 7 Rupert Street, Footscray West, W.12, Vict.

GENERAL INDEX

Summary

GENERAL INDEX

Names printed in italics as separate entries indicate that the forms are new to science.

CONTENTS